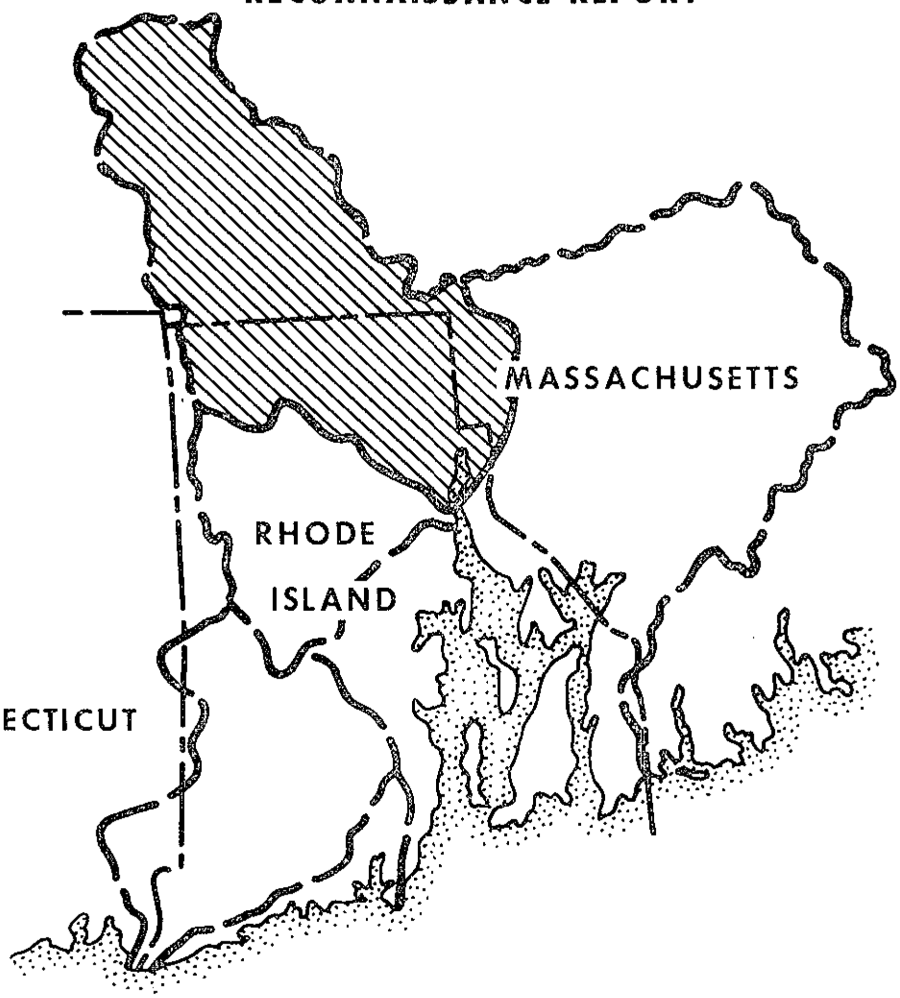
WATER AND RELATED LAND RESOURCES INVESTIGATION

PAWCATUCK RIVER AND NARRAGANSETT BAY DRAINAGE BASINS

PROVIDENCE RIVER GROUP WATERSHED RECONNAISSANCE REPORT



DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

OCTOBER 1972

SYLLABUS

In accordance with authorizing Congressional resolutions, the reconnaissance report of the Providence River Group watershed is oriented toward producing a flood management program to reduce and prevent flood losses in areas which have experienced or are critically susceptible to flooding. However, during the progress of this report it became apparent that in order to avoid the development of a plan which might preclude optimum use of the basin's water and related land resources, a re-orientation of the study to include urban studies for the Blackstone River sub-watershed should be considered.

This sub-watershed is an interstate area and its potential, for example, to satisfy urban demands through environmental enhancement is substantial. With anticipated population growth, the present environment will be hard-pressed to meet the demands imposed by the people and business in the area located between the urban centers of Boston, Worcester, and Providence. Additional recreation activities, such as boating and fishing along the main stem rivers and the already popular Narragansett Bay itself would provide increased benefits.

Water quality levels above those presently included in the State implementation programs could also help to stimulate the economic activity within the area. Water-dependent industries attracted to the basin because of increased water quality could help relieve the major employment void left by the declining textile industry in south-central Massachusetts and northern Rhode Island.

Re-orientation of this study has been discussed with the Chief, Planning Division, Office of the Chief of Engineers. To date no indorsement has been received from the involved States although it is anticipated that a request will be made for an urban study to provide a complete water and related land resource plan for the urban environment of the Blackstone River.

The additional cost to re-orient the study would be $900,000 with major portions of the work to be accomplished by contract service. This $900,000 would be in addition to the $1,600,000 previously budgeted for the total PNB Study. The study, commencing in FY 1974 will be carried out over a two-year period, terminating concurrently with submission of the PD report. In FY 1974, $250,000 would be expended and $650,000 in FY 1975. A plan of study will be prepared when the urban study program is undertaken.

PAWCATUCK RIVER AND
NARRAGANSETT BAY DRAINAGE BASINS
PROVIDENCE RIVER WATERSHED
RECONNAISSANCE REPORT

TABLE OF CONTENTS

PAWCATUCK RIVER AND NARRAGANSETT BAY DRAINAGE BASINS PROVIDENCE RIVER GROUP WATERSHED

RECONNAISSANCE REPORT

I. INTRODUCTION

This report is the second in a series of reconnaissance reports on major watersheds of the Pawcatuck River and Narragansett Bay Drainage Basins (PNB) study area. An initial "Plan of Survey" on the PNB, submitted in June 1970, was followed by a preliminary analysis and field reconnaissance revealing that certain communities within the total study area have suffered, in varying degrees, during the past two centuries from destructive floods. Under the present trend of continuing, uncontrolled growth in flood-prone areas, numerous localities will be subjected in the future to even greater flood losses from recurring storms with magnitudes equalling the August 1955 and the March 1968 floods.

The interests of the regional and national economies call for immediate initiation of a study interim report scope to provide a solution to the ever-critical flood and related problems of the Providence River Group (PD) drainage area. Therefore, this reconnaissance report is submitted as a working document to outline and expedite such a study. This management plan will be closely coordinated with the needs and recommendations now being developed by the on-going regional study of Southeastern New England (SENE), which is scheduled for completion in 1975 under the direction of the New England River Basins Commission.

II. AUTHORITY

Authority for the Providence River Group reconnaissance report is vested in seven outstanding resolutions combined under one resolve adopted 29 March 1968 by the Committee on Public Works of the United States Senate. In view of the heavy damages suffered during the storm of March 1968, in southern New England, the Board of Engineers for Rivers and Harbors was requested under this resolve to review the advisability of improvements in the interest of flood control, navigation, water supply, water quality control, recreation, low-flow augmentation and other allied water uses within the Pawcatuck River Basin, Rhode Island, and in the Narragansett Bay Drainage Basin, Massachusetts and Rhode Island.

III. LOCATION AND RELATIONSHIP OF PROVIDENCE RIVER WATERSHED TO TOTAL STUDY AREA

The PD watershed is one of five segments forming the Pawcatuck River-Narragansett Bay Drainage Basins (PNB) study area which lies entirely within the Southeastern New England (SENE) territorial study area. SENE, which is a level B study of survey scope covering 4,570 square miles, deals with a broad and comprehensive approach in the development of programs for meeting an array of resource needs and solutions to problems within Southeastern New England.

The PNB area is a level C study with a basic objective of formulating and recommending for authorization specific plans of improvements for flood control, navigation and related water purposes to meet present and long-term needs. It encompasses the Pawcatuck River Basin located in southwestern Rhode Island and southeastern Connecticut, and all the watersheds tributary to Narragansett Bay and the Atlantic Ocean from the Massachusetts-Rhode Island state line westward to Point Judith, Rhode Island. Its total drainage area consisting of 2,173 square miles, of which 1,076 square miles are situated in Rhode Island, 57 square miles in Connecticut, and the remaining 1,040 square miles in Massachusetts, accounts for approximately 47 percent of the total SENE area.

As shown in Figure 1, the Providence River Group (PD) lies in the northwesterly quadrant of the study area within the boundaries of the State of Rhode Island and the Commonwealth of Massachusetts. It is surrounded by seven watersheds, three of which are entities of the PNB Study area, the Pawtuxet (PX) on the southwest, the Coastal Drainage System on the southeast and the Taunton on the east side. Northeasterly of the PD area and comprising a major segment of the Southeastern New England (SENE) study is the Charles River Basin. Three other basins not identified in Figure 1, but flanking the PD area in a counterclockwise directions, are the Merrimack, Connecticut and Thames River Watersheds.

IV. DESCRIPTION OF PROVIDENCE RIVER GROUP

A. <u>General.</u> The Providence River Group embraces the entire northern area of the State of Rhode Island and a central section of Massachusetts from Worcester south to the Rhode Island State boundary. Communities which are wholly or partially located within this watershed number 40 towns and 9 cities of which 8 towns and 7 cities are in Rhode Island. These communities, together with population and area data, are listed in Table 3, on pages 23 and 24.

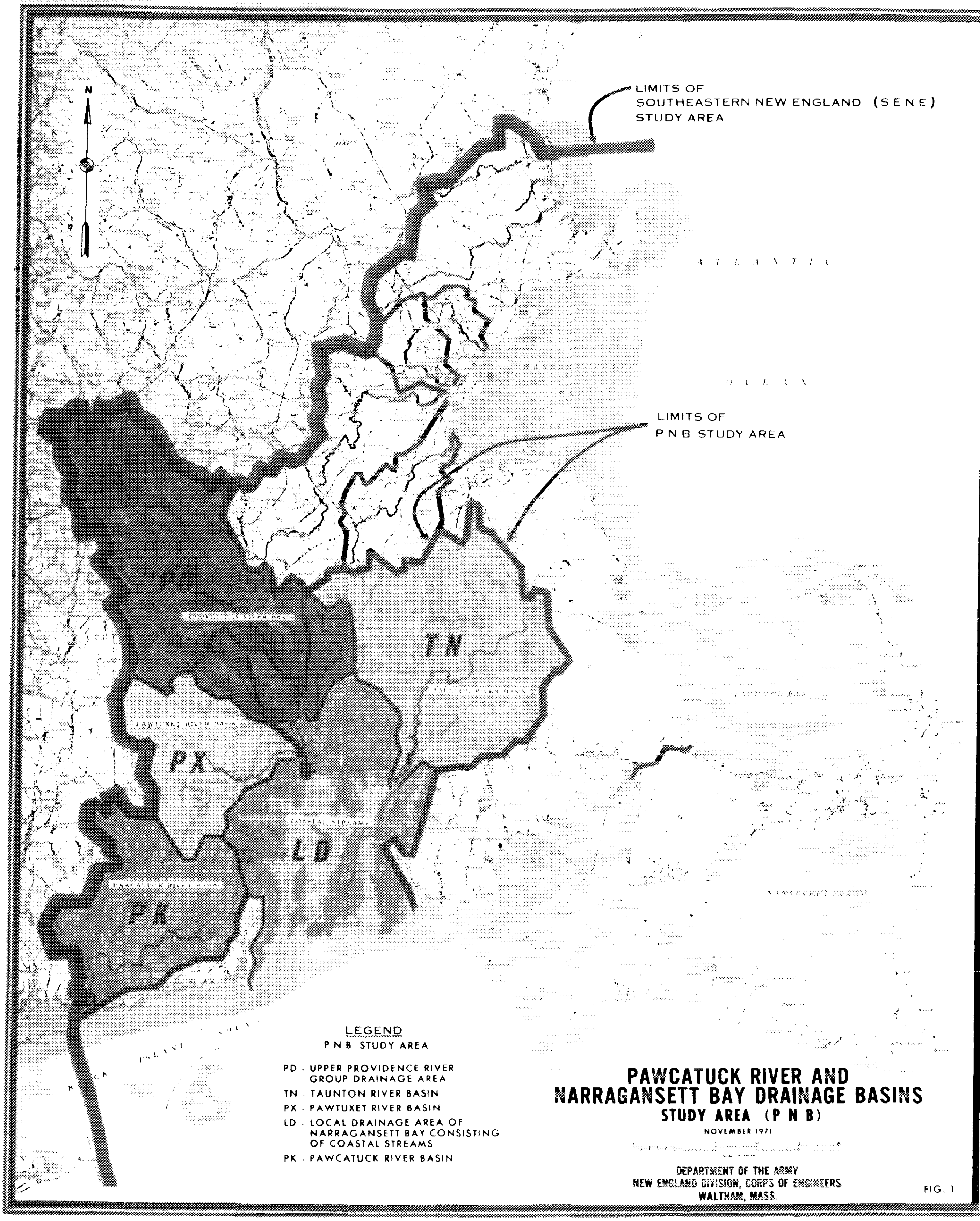

N
LIMITS OF
SOUTHEASTERN NEW ENGLAND (S E N E)
STUDY AREA
LIMITS OF
P N B STUDY AREA
PD
TN
PX
LD
PK
LEGEND
P N B STUDY AREA
PD - UPPER PROVIDENCE RIVER GROUP DRAINAGE AREA
TN - TAUNTON RIVER BASIN
PX - PAWTUXET RIVER BASIN
LD - LOCAL DRAINAGE AREA OF NARRAGANSETT BAY CONSISTING OF COASTAL STREAMS
PK - PAWCATUCK RIVER BASIN
PAWCATUCK RIVER AND
NARRAGANSETT BAY DRAINAGE BASINS
STUDY AREA (P N B)
NOVEMBER 1971
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

FIG. 1

The Providence River Group watershed is comprised of three sub-watersheds known as the Woonasquatucket, Moshassuck and the tri-river complex involving the Seekonk-Ten Mile-Blackstone Rivers. All combined, the total drainage area involves 615 square miles of which 233 square miles are situated in Rhode Island; the remaining 382 square miles located in Massachusetts account for approximately 62% of the watershed. The tributary drainage areas are tabulated in Table 1 and those of primary concern are explained in the following paragraphs. The watershed with tributary streams is shown on Plate No. 1.

TABLE 1

PROVIDENCE RIVER GROUP WATERSHED DRAINAGE AREAS
(Square Miles)

Rivers		Major Tributaries	Total
Woonasquatucket			51
Stillwater		17	
Other drainage		34	
Moshassuck			24
West River		11	
Other drainage		13	
Seekonk			540
Ten Mile		55	
Seven Mile	13		
Bungay	7		
Other drainage	35		
Blackstone		476	
Abbott Run	27		
Peters	12		
Mill	35		
Branch	96		
West	35		
Mumford	58		
Quinsigamond	37		
Middle	65		
Other drainage	111		
Local		9	
TOTALS		615	615

B. Providence River. For the purpose of this study, the mouth of the Providence River is defined as a line between City Wharf in Providence and Wilkes Barre Pier in East Providence where the Seekonk River joins the Providence River. From this point, the Providence River extends northerly for 1.2 river miles where it is formed by the confluence of the Moshassuck and Woonasquatucket Rivers in Providence, Rhode Island. Located about 0.2 miles upstream of the mouth of the Providence River is the completed Fox Point hurricane flood protection barrier which became operational in 1965. This project, originally authorized in 1958, protects a major portion of the commercial and industrial center of the city of Providence against tidal flooding.

C. Major Tributaries

1. Woonasquatucket River. The Woonasquatucket River rises in the towns of North Smithfield, Smithfield and Glocester, Rhode Island and follows a general southeasterly direction through numerous reservoirs, lakes and old mill ponds joining several smaller tributaries along the way to its mouth. The river, having a drainage area of about 51 square miles, measures approximately 19 miles in length, and is elongated, rather narrow, and oriented along a northwest-southeast axis. The upper half of the watershed, primarily a rural area cluttered with small, old mill ponds, is sparsely inhabited but show signs of increasing urbanization. The commercialized and industrial areas are concentrated for the most part in the major population centers of Providence, North Providence and Johnston, particularly adjacent to the main stem of the Woonasquatucket River.

2. Moshassuck River. The Moshassuck River watershed originates in the rural town of Lincoln, Rhode Island and meanders in a southerly direction through the western limits of the city of Pawtucket to join the Woonasquatucket River and form the Providence River at Providence, Rhode Island. It has a total drainage area of 24 square miles, of which its major tributary the West River makes up 11 square miles. The West River as its name indicates enters the Moshassuck from the west. Although this watershed has a small drainage area, it is located in a very densely populated section of Rhode Island. The upper half of the watershed consists primarily of residential development and interspersed commercial service centers. Heavy industrial concentration has been centered mostly in the lower end of the basin where new highway construction has provided the impetus for its revitalization.

3. Seekonk-Ten Mile-Blackstone Rivers

(a) Seekonk River. Entering the easterly arm of the Providence River is the Seekonk River which, together with its tributaries, drains an area of 540 square miles. By definition, it originates at Main Street Bridge in Pawtucket, Rhode Island, where the Blackstone River terminates, although hydraulically it is an extension of the Blackstone River. From this point it flows downstream, southerly through the city of Pawtucket and forms the boundary between East Providence and Providence. At river mile 4.5, it is joined by the Ten Mile River in the community of Rumford in East Providence. It then continues for another 2.5 miles in the same general direction to its terminal point at Wilkes Barre Pier. This entire 7-mile estuary is tidal and, exclusive of a short stretch of approximately 0.4 miles downstream of the dam at Main Street Bridge in Pawtucket, is navigable and principally used for receipt of petroleum products.

(b) Ten Mile River. This river is situated in the most eastern part of the Seekonk River Basin and drains an area of approximately 55 square miles. It originates in Massachusetts near the Wrentham-Plainville town line and flows in a southerly direction through the town of North Attleboro, the city of Attleboro and then the town of Seekonk, all in Massachusetts. It then flows along near the Rhode Island-Massachusetts boundary line to a point about one-half mile south of East Providence Center where it turns abruptly to the northwest and empties into the Seekonk River in the community of Rumford in East Providence, Rhode Island.

Tributaries of importance are the Seven Mile and Bungay Rivers with respective drainage areas of 13 and 7 square miles. The Seven Mile joins the main stem of the Ten Mile River just below the State line; the Bungay River enters the Ten Mile River northeasterly of Attleboro, Massachusetts.

In the Rhode Island portion, the Ten Mile River Basin is a highly developed watershed with commercial, industrial, and residential activities covering approximately 85% of the basin's acreage. In Massachusetts, the basin has extensive wetlands, numerous lakes and ponds, and man-made reservoirs, but also qualifies as a highly commercialized and industrialized area particularly in reference to the manufacture of jewelry and related products.

(c) Blackstone River. The Blackstone River Basin extends through south central Massachusetts and northern Rhode Island and covers approximately 334 and 142 square miles respectively of each state. It originates at the confluence of the Middle River and Mill Brook in the southeastern part of the city of Worcester, Massachusetts. Throughout most of its 44 mile length, this elongated shaped river basin with an average width of 12 miles flows in an irregular southeasterly direction, successively through the Massachusetts towns of Millbury, Sutton, Grafton, Northbridge, Uxbridge, Millville, and Blackstone. It continues on approximately the same course in Rhode Island through the city of Woonsocket, forms the boundary between the towns of Lincoln and Cumberland, and passes through the cities of Central Falls and Pawtucket. Its upper 27 miles are in Massachusetts, and the remaining 17 miles in Rhode Island.

Tributaries of significance, expressed in the downstream order in which they join the main river, are: the headwaters of the Blackstone River (consisting of Kettle, Beaver and Mill Brooks and Middle River); the Quinsigamond, West, Mumford, Branch, Mill, and Peter Rivers; and Abbott Run.

(1) Headwater Tributaries

a) Kettle Brook, located entirely in Massachusetts, drains 32.8 square miles and originates in the uppermost northwesterly part of the watershed at Reservoir No. 4 near Paxton Center in the town of Paxton. The brook flows southeasterly through the town of Leicester into the town of Auburn where at Stoneville it turns northerly toward Worcester. The terminus of Kettle Brook is at the outlet of Curtis Pond at the confluence of Beaver Brook, this point marking the beginning of the Middle River. In its entire length of 12.7 miles, Kettle Brook has been extensively developed with reservoirs for providing water supply to the city of Worcester and low-flow augmentation for downstream industrial purposes.

The principal tributary of Kettle Brook is Ramshorn Brook with a drainage area of 10.9 square miles. It originates in Ramshorn Pond in the towns of Sutton and Millbury and flows northerly to its confluence with Kettle Brook at Leesville Pond in Auburn near the intake of the Worcester Diversion tunnel. The tunnel was constructed for diverting flood flows in Kettle Brook away from the city of Worcester.

b) Beaver Brook with a drainage area of 15.6 square miles rises along the northern city boundary of Worcester approximately $1\frac{1}{4}$ miles westerly of Indian Lake. It flows southward to join Kettle Brook and form the Middle River at the outlet of Curtis Pond. Approximately 4.2 miles upstream from its terminus, it intercepts its major tributary, Tatnuck Brook on the westerly side. Tatnuck Brook having a drainage area of 11.3 square miles, originates in the town of Paxton in Holden Reservoir which is part of the city of Worcester water supply system. From its origin, it flows in a southeasterly direction through Cook Pond, Patch and Coes Reservoir, all in Worcester, to join Beaver Brook.

Unlike Tatnuck Brook watershed, which is primarily wooded and quite sparsely settled, the Beaver Brook watershed is densely populated with approximately 50% of its area heavily developed. Also unlike Tatnuck Brook, Beaver Brook has no appreciable ponds, lakes or reservoirs.

c) Mill Brook, located on the easterly side of Beaver Brook watershed and draining approximately 15 square miles, originates near Chaffinville, in the town of Holden. It flows southward through Indian Lake and thence through the center of Worcester to join the Middle River on the southern side of the city. Throughout most of its length, particularly in its most densely populated section below Indian Lake, Mill Brook is inclosed in an underground conduit. Other than Indian Lake, Marshall and Salisbury Ponds, there are very few ponds or wetland areas. The terrain is hilly and heavily urbanized.

d) Middle River. As described previously, the confluence of Beaver Brook with Kettle Brook at the Curtis Pond outlet forms the Middle River. From this origin, the Middle River flows generally southeasterly for a distance of approximately 2.5 miles through a wetland area, and two ponds and then intercepts Mill Brook to form the Blackstone River at the American Steel and Wire Company dam northeast of Quinsigamond Village in Worcester. At this point, it has a total drainage area of about 65 square miles of which 1.7 square miles is local and lies entirely within the limits of the city of Worcester and the town of Auburn.

(2) Quinsigamond River. This basin lies in the towns of Boylston, West Boylston, Shrewsbury, Grafton, Millbury and the city of Worcester. It has a length of 12.2 miles oriented along a north-south axis, a maximum width of 4.5 miles and drains an area of 37 square miles. The river measures about 13 miles in length, of which 8 miles is a succession of lakes, the largest being Lake Quinsigamond

with a water surface of 539 acres. This lake is one of three closely related bodies of water (combined area = 929 acres), the other two being Flints Pond with an area of 322 acres, and Hovey Pond with an area of 68 acres.

These three lakes have influenced and been chiefly responsible for the development of the watershed. The upper half of the watershed is densely urbanized and the lower half is predominantly and characteristically more rural. Areas along the periphery of the lakes have been heavily developed with year-round residential properties and land opportunities along the shores are limited. A continued growth of the watershed away from the water bodies is expected as the exodus of people from the core city of Worcester exerts pressures for a country atmosphere of living.

(3) West River. The West River, located entirely in Massachusetts, rises in Upton State Forest in the southwest corner of Westboro, three miles northeast of the center of Grafton. It flows in a southerly direction through the towns of Upton and Northbridge joining the Blackstone River about 0.6 miles downstream from the confluence of the Mumford and Blackstone Rivers. In a clockwise direction from its source in the headwaters, Hopkinton, Mendon and Millville are other perimeter towns within the watershed.

This watershed, elongated in shape with a maximum length of about 12.5 miles and a width varying from about 5 miles in the upper portion to approximately 2 miles in the lower section, has a total drainage area of 35 square miles, with 80% (27.9 square miles) controlled by the existing Corps of Engineers' West Hill flood control reservoir. This reservoir, completed in 1960 and located approximately 3.2 miles upstream from the mouth of the West River serves two purposes; stores flood waters providing stage reductions at downstream communities as far south as Pawtucket, Rhode Island; and recreation for satisfying the diversified recreational needs of the local populace.

The basin consists of low, rolling wooded hills and broad valleys with scattered small ponds and swampy areas. It is rural and sparsely inhabited with current trends indicating a status quo.

(4) Mumford River. The Mumford River originates from a system of lakes, ponds and reservoirs in the towns of Oxford, Douglas and Sutton, Massachusetts. It follows a rather sinuous course in a general easterly direction through the towns of Sutton, Northbridge and Uxbridge, Massachusetts, where it joins the Blackstone River 0.5 miles east of the business center of Uxbridge.

The basin has a length of 10.9 miles, a maximum width of 8.1 miles and drains an area of 58 square miles. Scattered throughout the area are several small and large impoundments which are principally utilized for storing process water for finishing textile goods.

The lower half of the basin is moderately urbanized and heavily industrialized, with textiles and machinery the chief manufactured products. Exclusive of some small scale residential developments, the upper half of the valley maintains a rural-suburban atmosphere. The native population works in larger neighboring communities since the few remaining, small and old local textile mills are unable to provide sufficient employment.

(5) Branch River. In terms of drainage area, the largest tributary of the Blackstone River is the Branch River (drainage area 96 square miles) 12.6 miles of which are in Massachusetts, while the remainder is in Rhode Island. The basin is shaped like an equilateral triangle, with each side approximately 15 miles long.

The main stem of the Branch River is formed by the confluence of the Pascoag and Chepachet Rivers near the village of Oakland in the town of Burrillville, Rhode Island, and terminates at the Blackstone River in Blackstone, Massachusetts, about 1.8 miles upstream of the Massachusetts-Rhode Island state line. Its northern fork (drainage area 46.9 square miles) originates on the Clear River at Wallum Lake near the state line and flows in a southeasterly direction to form the Pascoag and then the Branch Rivers. The southern branch, (drainage area 21.6 square miles), entirely in the State of Rhode Island, originates in the swamps upstream of Smith and Sayles Reservoirs in Glocester and flows in a northeasterly direction through the village of Chepachet to form the Branch River.

Scattered throughout this hilly terrain are many lakes, ponds and artificial reservoirs which were originally developed for processing of industrial goods in connection with textile manufacturing and finishing. Most of the villages are located in the valleys along the main stem and its principal tributaries. They are industrial in character and moderately urbanized. Other areas are rural and sparsely inhabited.

(6) Mill River. The Mill River has its source at North Pond in the towns of Hopkinton, Upton and Milford, Massachusetts. It flows southerly for 15 miles through the towns of Mendon and Blackstone, Massachusetts to the Blackstone River, a short distance above the U.S. Geological Survey gaging station at Woonsocket, Rhode Island.

The basin (drainage area 35 square miles) is almost entirely located within the Commonwealth of Massachusetts. Its shape is decidedly elongated, being 10 miles long with an average width slightly in excess of 2 miles. The Massachusetts portion of the watershed, consisting of low rolling, wooded hills and broad valleys with interspersed old mill ponds and swampy areas, is moderately inhabited and is best described as urban-rural. The Rhode Island section is predominantly a heavily populated residential area serviced by extensive commercial establishments and a few industrial complexes providing occupational opportunities. As a progressive step in the revitalization of the area, an urban renewal program involving three elements of multi-story housing for the elderly has been completed with other sections currently under investigation for urban redevelopment.

The largest impoundment within the basin is Harris Pond located almost entirely within the town of Blackstone, Massachusetts, with the dam and appurtenant structures straddling the Woonsocket city limits on the Rhode Island-Massachusetts state line. During the record flood of August 1955, this dam failed and compounded the flood problems within one section in the northern quadrant of the city of Woonsocket. Since then it has been rebuilt by Woonsocket as one of its main sources of water supply.

Subsequent to this disastrous flood, the Lower Woonsocket Local Protection Project was authorized and constructed. This project has 4,950 feet of channel improvement along the Blackstone, Mill and Peters Rivers and 2,300 feet of pressure conduits on the Mill and Peters Rivers. The Mill River and Peters River enter the Blackstone River in adjacent pressure conduits.

(7) Peters River. The Peters River has its origin north of Silver Lake in Bellingham, Massachusetts. From Silver Lake, Peters River flows southerly for approximately 3.5 miles before crossing the Massachusetts-Rhode Island state line at Woonsocket, Rhode Island. Approximately 1 mile further downstream, the Peters River joins the Blackstone River in a pressure conduit at the Lower Woonsocket Local Protection Project as descrived previously. The river basin averages about 2 miles wide and 5 miles long and has a drainage area of 12 square miles.

The upper portion of the Peters River watershed is rather sparsely populated, but proceeding downstream the area becomes more densely populated as the river approaches the community of Crooks Corner in Bellingham, Mass. In its last 2 miles the Peters River flows adjacent to and through a densely populated urban area. Near its confluence with the Blackstone River, there are a few industrial developments and extensive commercial establishments.

(8) Abbott Run. Abbott Run Brook originates respectively, in the towns of Wrentham and Cumberland along the Massachusetts and Rhode Island State line. A short distance from its origin, it is impounded in the Diamond Hill Reservoir which supplies water for the city of Pawtucket, Rhode Island. From Diamond Hill Reservoir, Abbott Run flows south for about 2 miles through some small ponds and crosses the Rhode Island-Massachusetts State line into North Attleboro, Massachusetts. It then meanders in a southerly direction for another three miles, and once again crosses the State line. Abbott Run joins the Blackstone River in the village of Valley Falls in Cumberland, Rhode Island.

The watershed is some 11 miles long and roughly 3 miles wide with a total drainage area of 27 square miles. It is characterized by many swamps and several small ponds with hilly topography more pronounced along the outer fringes. The northern section is sparsely inhabited and considered rural in character, while the lower section is moderately urbanized.

V. FLOODING AND FLOOD PRONE AREAS

A. River Flooding

In the last two centuries, the Providence River Group watershed has experienced many outstanding floods, some of which caused substantial damage. In general, the flood damages have been directly associated with: - a lack of, or non-enforcement of, zoning ordinances; dam failures; poor river channel maintenance; flood plain encroachment; and inadequate channel capacity. More recently, uncontrolled urbanization, coupled with highway construction and extensive commercial and industrial development have markedly increased the flood damage potential of this watershed.

Recorded floods in the watershed date back to March 1818, but little is known about the character and extent of early floods. Significant storms which have produced severe flooding and which are historically documented occurred in February, 1886; March, 1936; July, 1938; August 1955; and March, 1968. Other floods of significant magnitude but less infamous, occurred in March, 1818; March 1876 and 1877; September, 1887; October, 1895; November, 1927; and September 1932.

The United States Geological Survey maintains gaging stations at several locations on various streams in the watershed. The principal gage on the Blackstone River is located at Woonsocket, Rhode Island and has been in operation since 1929. It has a drainage area of 416 square miles. A gage on the Woonasquatucket River at Centerdale, Rhode Island with a drainage area of 38.3 square miles, has been in operation since July 1941. A gage with a drainage area of 23.1 square miles has been in operation on the Moshassuck River at Providence, Rhode Island since June 1963. There is no gaging station on the Ten Mile River, but its run-off characteristics are believed somewhat similar to those of the Woonasquatucket and Moshassuck Rivers.

Following is a list of the greatest flows of record at the above gaging stations plus some computed flows for the 1936 flood based on flows over dams.

Station	Drainage Area (sq.mi.)	Record	Discharge (cfs)	Date
Blackstone River Woonsocket, R. I.	416	1929-Date	32,900	Aug 1955
			15,400	Mar 1968
			15,100	Jul 1938
			15,000	Mar 1936
			9,400	Sep 1954

Station	Drainage Area (sq.mi.)	Record	Discharge	Date
Woonasquatucket R. Centerdale, R. I.	38.3	1948-Date	1,440	Mar 1968
			1,100	Sep 1954
			1,000**	Mar 1936
			4,220*	Feb 1886
Moshassuck River	23.1	1964-Date	2,390	Mar 1968
			1,110	Aug 1967
			650**	Mar 1936
Ten Mile River East Providence, R. I.	53.7		1,050**	Mar 1936

*Data supplied by the former Rhode Island State Planning Board and published in prior report.

**Computed from flow over dam.

Flood development varies among the sub-watersheds in the PD basin. Some are subject to flooding as a result of high volume rainfall, particularly in the spring during high antecedent moisture conditions, such as were experienced in March 1968. Others are susceptible to flooding at any time due to high intensity rainfall, such as experienced on the Blackstone River in August 1955. Each major sub-watershed is discussed separately in the following paragraphs.

Blackstone River

a) General

The Blackstone River has suffered more from flooding than the other rivers in the Providence River Group watershed. Storms causing flooding date back to 1877. Prior to 1936, records of destructive floods are incomplete, consequently, little can be said about the extent and characteristics of the flood problems of those early storms. With installation of various gaging stations along the river since 1934 recorded peak flows for the floods of March 1936, July 1938, August 1955, and March 1968 have provided sufficient data for hydrological analyses to indicate that the August 1955 flood can be considered the greatest flood ever recorded on the river. The March 1968 flood, though less severe, also subjected many areas to flooding.

In August 1955 "Hurricane Diane" deposited an average of 12 inches of rainfall over the watershed. Just a few days previous, "Hurricane Connie" had saturated the ground and filled the swamps, lakes, ponds, and reservoirs. The heavy precipitation, together with a low infiltration rate, caused unprecedented flood damages. Many communities along the main stem and tributaries were seriously affected. Losses were greatest in the cities of Worcester, Massachusetts and Woonsocket, Rhode Island. Many dams were breached or severely damaged, thus intensifying flood conditions in many localities. Railroad and highway facilities and water, sewage, and electrical utilities were either severed or drastically disrupted.

Subsequent to August 1955, three Corps local protection projects and one flood control reservoir were constructed. The projects were the Upper and Lower Woonsocket, Rhode Island Local Protection Projects; and the Worcester Diversion Project and West Hill Reservoir in Massachusetts. Throughout the Blackstone River the Commonwealth of Massachusetts undertook costly rehabilitation programs of various damaged areas.

Random industrial and commercial growth throughout the basin, including encroachment along the flood plains, has adversely changed the hydrologic characteristics of the watershed. Current trends toward flood plain development point to a continual and more rapid expansion of these lands. Zoning constraints are practically non-existent; some type of restriction must be enforced if future flood problems are to be adequately controlled.

b) Main Stem

There are many areas along the main stem of the Blackstone River which have experienced flooding and are still susceptible to future flooding. Many commercial and industrial districts in Pawtucket, Rhode Island have been protected against floods as a result of urban renewal programs in the city. However, one major downtown district could experience damages from a flood of the magnitude of the August 1955 flood. The city of Central Falls, Rhode Island is a congested area which is heavily industrialized along the flood plains. Consequently, the mill buildings now housing a variety of businesses are subjected to sporadic and severe flooding. Industrial and commercial complexes built on the flood plains are also present in Cumberland and Lincoln, Rhode Island. Commercial and industrial expansion onto these vacant flood plains is a result of their proximity to suitable transportation facilities and to large urban centers. Old, flood prone industrial plants along the banks of the Blackstone River are also present in and near Woonsocket, Rhode Island. The major damage center is the moderately industrialized area between the upper and lower Corps of Engineers flood protective works. Once economically prohibitive to remedy, recent highway construction has altered the flooding characteristics of the area and could result in severe flood damages.

Recurring damages from the Massachusetts-Rhode Island State line to Worcester, Massachusetts have been a constant source of aggravation to the businesses occupying the former textile mills and to the communities built along the banks of the river. The lack of upstream, water-related land management affecting the run-off characteristics of the watershed has made previously flood prone downstream areas susceptible to even greater flooding.

c) Tributaries

The Branch River, controlling approximately 20 percent of the Blackstone River watershed, is the largest tributary of major importance in both States, and a major contributor to flood peaks along the main stem. It is essentially an industrial stream serving the few remaining textile industries in the basin. The watershed is sparsely inhabited. Most of the population centers are small villages scattered along various headwater streams. The watershed has an abundance of industrial water impoundments which are either obsolete or converted to recreational sites. Most impoundments have negligible capability to provide minor flood control. Numerous communities and villages along the stream banks were subjected to moderate flooding in March 1968. Little or no future industrial or commercial growth is anticipated for these areas. Encroachment along these streams must not be allowed if flood flows in the Blackstone River are to be reasonably controlled.

Many of the other tributaries in Rhode Island are susceptible to future flooding because of hydrological changes caused by urbanization. Flooding in the tributary areas can generally be attributed to local drainage problems such as inadequate bridge or culvert openings, excessive debris and vegetation in the streams, and domestic and commercial fill-in operations along the flood plains.

An important area of flood control concern along the Massachusetts tributaries are the headwaters of the Blackstone River. They account for approximately 14 percent of the watershed. Originating outside the city limits of Worcester, Massachusetts, the streams travel through the city and converge in the southwest section to form the main stream. With changing run-off patterns in the upper basin (shift from rural to urban), it is questionable whether the basin can continue to rely on existing flood control measures to prevent flooding.

Woonasquatucket River

The Woonasquatucket River Basin has recorded flooding problems dating back to February 1886. Because of its small size, the proximity of the storm centers and antecedent run-off characteristics determine whether flooding will occur. Very few of the experienced storms in the PD area have been centered over the basin. The February 1886 storm produced the most extensive flooding conditions in the watershed. The center of the storm was so near the damage area that heavy precipitation, with attendant conditions, produced the greatest flood known in the basin. According to newspaper articles, the river was out of its banks, and the lowlands were flooded from its mouth in Providence to Waterman Reservoir in Glocester-Smithfield, Rhode Island. Though the storm of September 1932 produced heavy precipitation over the watershed, run-off conditions prevented destructive high water from accumulating.

Exclusive of the most recent storm of March 1968, many other notable storms of equal or greater magnitude have been recorded in the basin. Flood losses were minimal because of existing run-off conditions. The Woonasquatucket River watershed experienced a major flood with moderate damages occurring in the lower half of the river during the March 1968 storm. Most of the precipitation fell during two storms; the first storm was on 12 and 13 March, and the second on 17 to 19 March. Although the 12-13 March storm produced much less precipitation than the second storm, run-off from melting snow, together with precipitation contributed to severe flooding.

The communities located along the lower reaches of the Woonasquatucket River, below the United States Geological Survey gaging station at river mile 6.5 are heavily urbanized with characteristically rapid run-off. In March 1968, this area experienced moderate flood damage. Today, it is susceptible to even greater damage. Undersized bridge openings, constricted river channel, flood plain encroachment, insufficient channel maintenance, and non-enforcement of riparian dumping policies have led to minor flooding nearly annually.

The upper half of the watershed is primarily a rural area. It is clustered with many ponds, lakes, or reservoirs, formerly used as textile mill impoundments. With the decline of the textile industry many of these impoundments have been converted to recreational sites. The most pressing problem appears to be the structural instability of these impoundments under adverse conditions resulting primarily from lack of periodic maintenance and improper operating procedures. During the March 1968 flood, the water surfaces of some of these impoundments were lowered for fear of failure. Though associated damages were isolated, the possible failure of any of these structures could have posed a serious threat to downstream communities.

Moshassuck River

The Moshassuck River Basin is susceptible to the similar flooding conditions as its neighboring watershed, the Woonasquatucket River Basin. The lower portion of the main stem is heavily industrialized, interspersed with commercial and residential developments. The urban area of the watershed is serviced by an elaborate transportation system. The upper portion of the watershed is rural in character and not very prone to flood damage.

The community of Saylesville (town of Lincoln) has experienced moderate to heavy flooding. However, flooding to a lesser degree occurs in downstream reaches. Most of the flood damages have involved old industrial buildings in an industrial park. Commercial establishments and some residential properties have also suffered moderate flood losses. Should the upper portion of the Moshassuck River Basin become heavily urbanized, as projection trends seem to indicate, flooding conditions in the lower portion will be aggravated.

Development in the West River Basin, the major tributary of the Moshassuck River, has been more rapid than on the Moshassuck River. The upper portion of the West River watershed has been developed primarily for residential homes and occasional commercial centers; the lower portion of the watershed has acquired more of an industrial character. Swamps have been filled in and streams channeled into inadequate conduits. In many instances dams have been breached on old ponds and the peripheral lands reclaimed. Other portions of the stream have been altered by debris and inadequate bridge openings. Fast run-off characteristics, together with these urban watershed problems contribute to nearly annual flooding.

Ten Mile River

Flood damages along the Ten Mile River are centered near Attleboro and North Attleboro, Massachusetts. In Attleboro, the urban run-off characteristics which contribute to flooding are caused by restrictive man-made channels; undersized culverts and bridges; and dams which cause backwater flooding upstream of buildings and roads. In North Attleboro, flooding is due to inadequate culverts, new construction, and flood plain encroachment. The construction of an elaborate highway system has increased the desirability of vacant flood plains for commercial and industrial development. The change in run-off characteristics will increase the flooding potential of the existing problem areas as well as introduce new problems in recently developed areas.

Seekonk River

The 7-mile long Seekonk River is tidal and consequently is more subject to tidal flooding. Other than the low-lying areas situated along the shores of the river, particularly in Pawtucket, very little flooding has occurred as a direct result of riverine flooding. Moderate flooding of these areas would be experienced when high tides coincide with flood crests of the Blackstone and Ten Mile Rivers. Under these adverse conditions, flooding could be severe in the downtown district of Pawtucket and adjoining areas in East Providence and Providence. The Seekonk River, as affected by tidal flooding, is fully discussed in Part B of this section.

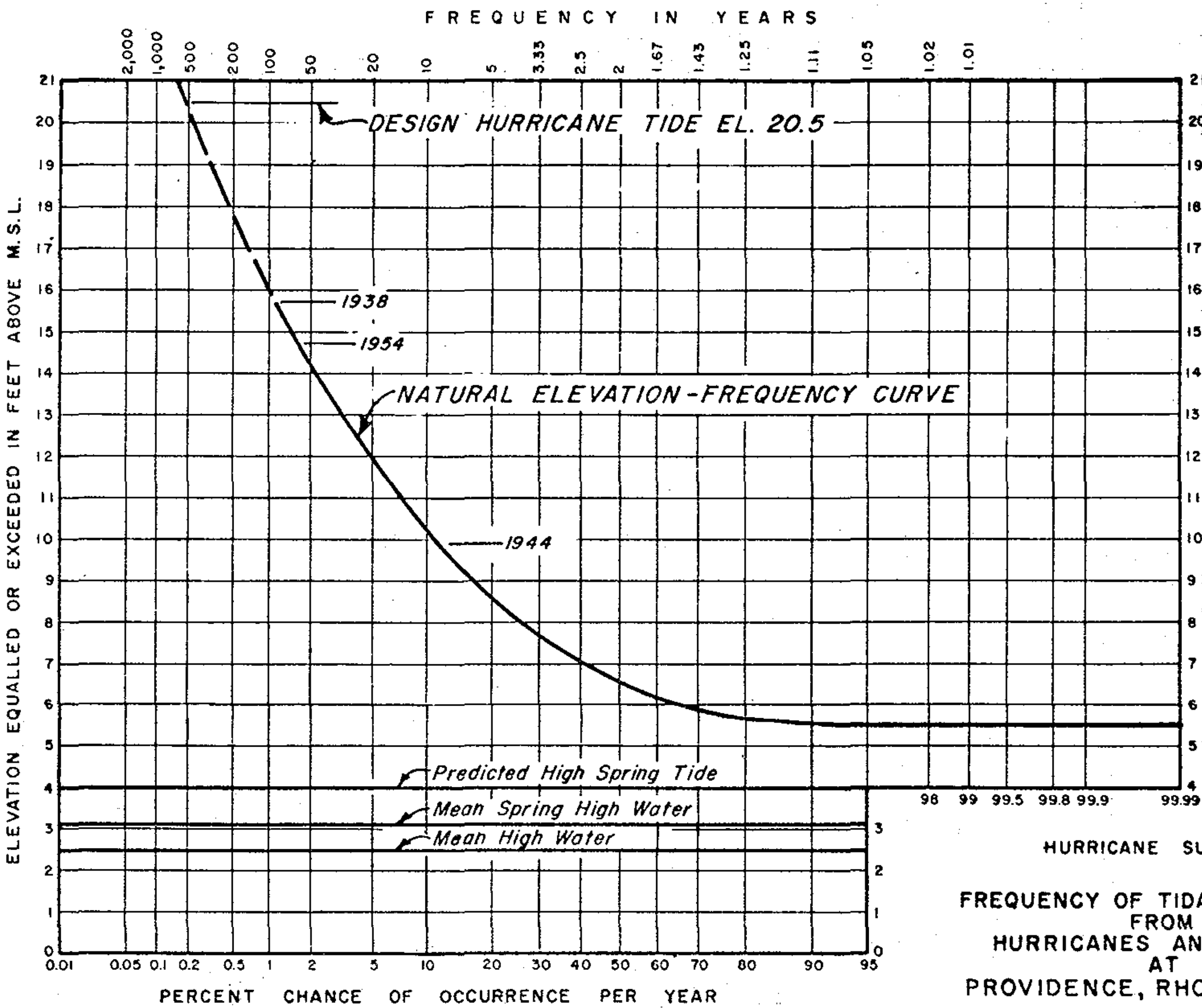
B. Tidal Flooding

The Providence River watershed is also susceptible to flooding from coastal storms of tropical or extra-tropical origin. Both major and minor tidal flood damages have been experienced along the Seekonk and the Upper Providence Rivers, including the Moshassuck and Woonasquatucket Rivers. Approximately 71 tropical storms of hurricane force have passed this area in the last 300 years. Of these, 13 have caused severe tidal flooding, 25 have caused moderate flooding and 33 others have threatened the area. Figure 2, derived from frequency data of notable storms (tabulated in Table 2), shows the frequency of tidal flooding from hurricane and tidal storms in Narragansett Bay at Providence, Rhode Island.

With the advent of the Fox Point Hurricane Barrier, completed in 1966 and located about one mile south of the heart of Providence, only 0.2 mile of the total 1.2 miles, referred to above, remains vulnerable to tidal flooding. This unprotected area predominantly contains oil terminal facilities scattered over a wide area; therefore, flood protective works appear economically questionable at this time.

The Seekonk River up to Slater Mill Dam in Pawtucket is also influenced by tidal fluctuation and is occasionally subjected to tidal flooding. About two-thirds of the westerly bank is rather high and steep and occupied by cemeteries, a campus-style hospital and the Blackstone Park none of which is readily subject to tidal flood damage. Though the remaining area of the westerly bank is prone to tidal flooding, the commercial, industrial, institutional, and recreational establishments within the locale are either scattered or of low monetary loss value.

The shoreline areas along the easterly side have sustained minor to moderate losses from tidal flooding. These low-lying shore areas are accessible by both coastal vessels and by elaborate highway and railroad systems. Accessibility by several modes of transportation is continuously



HURRICANE SURVEY

FREQUENCY OF TIDAL FLOODING FROM HURRICANES AND STORMS AT PROVIDENCE, RHODE ISLAND

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS. AUG. 1961

FIGURE 2

TIDAL ELEVATIONS VS FREQUENCY DATA
HURRICANES AND SEVERE STORMS
PROVIDENCE, RHODE ISLAND

TABLE 2

Hurricane or Storm		Maximum Tidal Elevation		Frequency Plotting Position (1) Percent Chance of Occurrence in any One Year		
		(ft., m. s. l.)		(1635-1963)	(1815-1963)	(1931-1963)
Hurricane	3 Aug 1638	18 ±	(2)	0.15		
Hurricane	15 Aug 1635	17 ±	(2)	0.46		
Hurricane	21 Sep 1938	15.7	(3)		0.34	1.52
Hurricane	31 Aug 1954	14.7	(3)		1.01	4.55
Hurricane	23 Sep 1815	14.2	(3)		1.68	
Hurricane	14 Sep 1944	9.9	(3)			7.58
Storm	7 Nov 1953	7.9	(4)			10.61
Hurricane	12 Sep 1960	7.9	(5)			13.64
Storm	30 Nov 1963	7.8	(5)			16.67
Storm	12 Nov 1947	7.3	(6)			19.70
Storm	7 Feb 1951	7.2	(6)			22.73
Storm	27 Jan 1933	7.1	(6)			25.76
Storm	3 Nov 1951	7.0	(6)			28.79
Storm	15 Feb 1953	6.9	(6)			31.82
Storm	31 Oct 1947	6.8	(6)			34.85
Storm	22 Oct 1949	6.8	(6)			37.88
Storm	25 Nov 1950	6.8	(7)			40.91
Storm	23 Oct 1953	6.8	(6)			43.94
Storm	1 Oct 1936	6.6	(6)			46.97
Storm	13 Apr 1953	6.6	(6)			50.00
Storm	30 Nov 1932	6.4	(6)			53.03
Storm	3 Mar 1942	6.4	(5)			56.06
Hurricane	12 Sep 1950	6.4	(6)			59.09
Storm	30 Nov 1944	6.2	(5)			62.12
Hurricane	29 Aug 1949	6.2	(6)			65.15
Storm	8 Dec 1950	6.2	(7)			68.18
Storm	22 Nov 1945	6.1	(5)			71.21
Hurricane	15 Oct 1954	5.9	(7)			74.24
Storm	7 Mar 1962	5.8	(5)			77.27
Storm	6 Dec 1962	5.8	(5)			80.30
Storm	3 Mar 1947	5.7	(5)			83.33
Storm	3 Apr 1958	5.6	(5)			86.36
Storm	19 Feb 1960	5.6	(5)			89.39
Storm	6 Mar 1943	5.5	(5)			92.42
Hurricane	11 Sep 1954	5.5	(7)			95.45
Storm	3 Jan 1960	5.5	(5)			98.48
Storm	14 Feb 1960	5.5	(5)			100.00

TIDAL ELEVATIONS VS FREQUENCY DATA
HURRICANES AND SEVERE STORMS
PROVIDENCE, RHODE ISLAND

TABLE 2 (cont'd)

(1) Calculated plotting position

$$P = \frac{100\ (M-0.5)}{Y}$$

where

P = percent chance of occurrence in any one year

M = number of the event

Y = number of years of record

(2) Estimated from historical account

(3) Based on high water mark elevations at Providence, Rhode Island

(4) Estimated by U. S. Coast and Geodetic Survey and stage related from Newport Harbor, Newport, Rhode Island to Providence, Rhode Island

(5) Based on record of U. S. Coast and Geodetic Survey recording tide gage located at State Pier No. 1, Providence, Rhode Island

(6) Based on record of U. S. Coast and Geodetic Survey recording tide gage located at Constellation Dock, Coasters Harbor Island, Newport, Rhode Island and stage related to Providence, Rhode Island

(7) Based on record of Narragansett Electric Company staff gage, located at South Street Station dock, Providence, Rhode Island

exerting pressure for the development of the remaining vacant land. Presently, most of these commercial and industrial complexes are scattered or susceptible to tidal flooding only on very rare occasions, so that economically justifiable flood protective works appear very remote. However, without adequate land use planning policies, this continuing growth could lead to very severe losses.

The Seekonk River, exclusive of a short 0.4 mile stretch downstream of the dam at Main Street Bridge in Pawtucket, is navigable with a 12-foot deep channel, maintained by this office. Along the channel are two abandoned draw bridges, one formerly handling highway traffic and the other a railroad trestle. Both of these structures, currently owned by the city of Providence, have been left in an opened position permitting unrestricted navigational traffic at all times, however, their complete removal should be seriously considered. The structures date from the early 1900's, and future maintenance may become a problem, resulting in their becoming an impediment to navigation. Removal could enhance the aesthetic value of the area and provide an incentive for the development of the estuary to recreational boating and associated facilities.

C. Combined River and Tidal Flooding

The previous two sections have discussed river and tidal flooding as somewhat independent problems. Such is not always the case. In the lower reaches of the streams there is a real possibility that the two problems could occur simultaneously, producing higher stages than either could by itself. Though considered a rare event this situation would be present if freshwater flood flows, resulting from hurricane rainfall, were to coincide with hurricane-induced tide levels.

VI. POPULATION TRENDS AND LAND USE PATTERNS

In 1970, there were about 723,000 people in the basin, a growth of 3 percent over the 1960 figure. Over 68 percent lived in eight basin cities; Worcester, Attleboro, Woonsocket, Pawtucket, Central Falls, Providence, and North and East Providence; the remainder were in forty smaller communities. The growth of 3.0 percent was substantially less than the growth of over 10 percent in the two States in which the basin is located and points up the still lingering effect of the textile industry debacle of the 1950's.

The textile industry, in combination with the jewelry industry, had been the economic backbone of much of the basin for years and set the pattern for its development. The textile mills located (with some exceptions) in the small communities along streams where water for power and processing were available; the jewelry industry developed in the more populous centers, especially in the southern part of the basin. Attleboro and North Attleboro in Massachusetts, Providence and Pawtucket in Rhode Island are among the more important jewelry centers. Only Worcester, in the basin's headwaters, and Providence at the river's mouth, have the broad, diversified industrial base necessary for economic growth and it is in the immediate suburbs of these cities that most of the basin's growth in population took place in the 1960 - 1970 period, although the core cities themselves lost population.

A major determinant in the basin's development was the Providence and Worcester Railroad, now a part of the Penn-Central System. One of the country's oldest railroads, it ran up the Blackstone River Valley and it was along its line that most of the communities which housed the textile industry grew up. The highway system between Providence and Worcester generally follows the Blackstone River Valley, although it often swings some distance away from the river itself. Routes 122 and 146 are the principal roads along the river's course. Route I-295, in Rhode Island, crosses the basin as a circumferential route around Providence, and due for completion within a few years will further stimulate the economy and growth of the area. The Massachusetts Turnpike and Route I-290 in Massachusetts cross the upper end of the basin in an east-west direction, but the cross valley roads along which development took place in Massachusetts were Routes 9 and U. S. 20 in the upper basin, and Route 16, across the lower basin. In Rhode Island, the road system is a more random one and gives ready access to most of the basin's communities.

The effect of the highway system in Massachusetts has been to promote linear development along the principal roads and little development elsewhere. Much of the middle portion of the basin is undeveloped,

5. Flood Proofing. There are many areas in the watershed wherein large scale structural methods of protection against flood losses would be economically infeasible and use of non-structural solutions would not be possible. For example, an isolated mill may be subjected to periodic and minor flooding. Here, partial bricking of windows, relocation of entrances, and waterproofing foundations may be sufficient to provide the needed flood protection. In the case of isolated residential properties, waterproofing basements, together with sump pump facilities may be the only economical solution available. Although the Federal Government cannot provide the necessary funds for implementing most of these flood proofing methods, the Corps of Engineers can provide, at the request of individuals, through their municipal government, free technical assistance by delineating flood probability and stages for the area of concern. It is expected that such flooding information developed in the interim report stage will be utilized extensively by local interests.

6. Urban Redevelopment. Urban redevelopment presents another opportunity for communities to remove developments from flood plains and place them in secure areas, safe from floods, and to make sure that new construction in the flood plains is designed to withstand flooding.

During the course of the interim report study, upon request, the evaluation of flood hazard areas as they relate to urban redevelopment will be fully investigated. Communities contemplating or actually planning urban redevelopment will be made aware of the technical assistance available to them.

7. Small Watershed Treatment. Under Public Law 566, the small watershed program which was enacted by Congress in 1954, localities which are able to demonstrate that multiple-purpose watershed projects can serve as an effective means in controlling land use and water problems for rural and urban communities can apply for Federal assistance. PL 566 projects are handled by the U. S. Department of Agriculture, Soil Conservation Service (SCS). In the Providence River watershed there are presently two such studies in progress, one on the Woonasquatucket River watershed, including the Moshassuck River, and a second on the Ten Mile watershed. Both studies will be coordinated with studies under way by the Corps of Engineers.

D. Non-Structural Measures.

Since earliest times, man has encroached upon the flood plains of rivers and streams. Today, with increasing population and accompanying basin and only limited present demand for it. Barring a large increase in the economic activities affecting the entire basin, it seems unlikely that there will be any changes in the core city to suburb migration patterns. However, commercial and industrial growth will tend to expand into the undeveloped land near or adjacent to the present transportation systems and within the tier of communities along the main stream of each sub-watershed. The outer fringes of the sub-basins should not be subjected to additional commercial, industrial, residential, and institutional pressure, but the localized commercial and industrial growth could aggravate present flood management problems.

TABLE 3

Massachusetts	Estimated 1970 Basin Population Total	Estimated % Growth 1960-1970	Area Within Basin % of Total Area
Towns			
Auburn	14,580	10	93.2
Bellingham	6,980	106	48.1
Blackstone	6,570	28	100.0
Boylston	420	17	20.1
Douglas	2,510	15	86.2
Foxborough	10	10	0.7
Franklin	180	70	9.3
Grafton	11,080	10	93.3
Holden	1,260	24	18.1
Hopedale	3,650	8	83.7
Hopkinton	600	21	14.0
Leicester	2,740	12	33.2
Mansfield	400	28	4.0
Mendon	2,520	22	98.7
Milford	1,940	23	14.6
Millbury	11,990	25	99.6
Millville	1,760	13	100.0
N. Attleborough	18,670	26	98.8
Northbridge	11,800	9	100.0
Oxford	520	11	5.0
Paxton	1,120	55	24.1
Plainville	3,720	30	55.7
Rehoboth	330	31	3.8
Seekonk	4,340	32	33.4
Shrewsbury	13,440	16	62.3
Sutton	4,590	26	98.2
Upton	3,480	11	96.7
Uxbridge	8,250	6	100.0
Webster	10	10	1.0
Westborough	130	31	2.6
West Boylston	320	15	8.4
Wrentham	2,200	10	30.2
Cities			
Attleboro	26,330	21	71.0
Worcester	176,570	-5	99.3

TABLE 3 (cont'd)

Rhode Island	Estimated 1970 Basin Population Total	Estimated % Growth 1960-1970	Area Within Basin % of Total Area
Towns			
Burrillville	9,080	11	85.3
Cumberland	26,610	42	100.0
Glocester	2,840	52	53.4
Johnston	11,020	28	27.9
Lincoln	16,180	19	100.0
N. Smithfield	9,350	23	100.0
Scituate	10	10	0.1
Smithfield	13,470	43	99.9
Cities			
Central Falls	18,720	-6	100.0
Cranston	730	9	1.0
E. Providence	14,450	15	31.3
N. Providence	24,340	34	100.0
Pawtucket	76,980	-5	100.0
Providence	107,530	-14	69.5
Woonsocket	46,820	-1	100.0
ESTIMATED TOTAL	723,140		
ROUNDED	723,000		

VII. PROBLEMS AND NEEDS

The general objective of the basin study is to formulate a flood management program which would foster an optimum plan of development within established water resources guidelines. To do this, the study must employ a comprehensive approach to the problems and needs of the watershed. In this manner, the resultant plan would reflect the ultimate values to be achieved in the wise utilization of basin water and related land resources. As an initial step, a preliminary assessment of flood related problems and needs in the Providence River Group watershed was made. Briefly these problems and needs are identified in the following paragraphs.

A. Continuing and Increasing Flood Problems. In step with the nation, the region located directly in the corridor of the Northeastern United States megalopolis has undergone recent dramatic transportation changes. An improved highway transportation system has improved mobility and opened up areas of the basin which were largely undeveloped in the past. The new state and interstate highway systems criss-crossing both the State of Rhode Island and the Commonwealth of Massachusetts have reduced commuting times so that greater areas of the basin are within reach of the urban complexes. With completion of the proposed highway network, there will be an even greater demand exerted on the resources of the basin.

The flood plains of the Blackstone River Valley proper are also playing a significant role in the development of the basin. Here, development has been revitalized on areas serviced by an existing railroad which runs parallel to the main stem of the Blackstone River. These areas appear to be the most economical to develop when considering the convenience of the rail system.

With the availability of rail transportation and improved highways, capable of providing efficient and excellent accessibility to the watershed, the population of the basin and its surrounding areas will increase and exert pressure on the region. Consequently, urbanization within the watershed will bring about tremendous physical land changes. Unless a timely flood management program is instituted, these changes could cause severe or catastrophic flood losses. To reduce flood hazards and lessen future flood damages, it is important that the study be geared to the development of a balanced flood management program encompassing both corrective and preventive measures.

B. Increased Demand for Water Supply. As the population and industrialization increase, there will be a growing demand for increased water supply within the basin. To insure the best use of watershed resources, flood control programs involving potential reservoir impoundments will examine water supply as a project feature.

C. Increased Demand for Recreational Opportunities. Since most of the existing reservoirs within the basin are operated primarily to maximize water supply for either domestic or industrial use, recreational opportunities are very limited. Other impoundments, operated solely for recreational activities are either so small or over-developed as to render their expansion economically prohibitive. To satisfy some of the needs of the growing population, while still maintaining the high quality of the present outdoor recreational facilities, recreational potentials, as a by-product of a flood control program, will be fully explored.

D. Low Flow Augmentation. Coordination with the on-going comprehensive study of Southeastern New England indicates that present flows in certain portions of streams preclude or impair the use of the basin's waters for many legitimate purposes. The gravity of this problem and the extent to which the needs can be phased in with the basin's flood control program has not yet been determined; however, the possibility of supplemental low flows to improve stream conditions for water quality, fish and wildlife enhancement, recreation, as well as increasing the aesthetic enjoyment will be investigated.

E. Flood Plain Management Program. There is no flood plain management program encompassing all flood-prone areas of the basin. In general, individual community plans are inadequate. Apparently the land requirements of our expanding economy and the economic advantages of developing flood plain lands are reflected in their intensified use. To temper the rate of such development and to preserve the remaining natural flood detention areas, the formulation of a managed-use plan will be a high priority in the flood control of the Providence River Group.

VIII. FLOOD LOSSES

A. General. Information concerning floods in the Providence River Basin extends back 150 years, but it has only been in the past 45 years that detailed information on floods has been gathered and reported.

The flood of record in the riverine portion of the basin was that of August 1955 which caused losses of $65.5 million. Over 60 percent of the losses were to industrial properties, 20 percent of the losses were urban, i.e., to residential, commercial, and public properties, and 16 percent of the losses accrued to transportation facilities, roads, and railroads. Remaining losses were to public utilities.

In the tidal portion of the river the flood of record was caused by the hurricane of 21 September 1938 but there is a dearth of information as to true flood losses as distinguished from hurricane losses in general. Hurricane "Carol" of August 1954 caused tides which were a foot lower than those of September 1938. Damages of over $31.5 million were experienced, principally in the city of Providence. The greatest losses by far were to commercial properties as the central, tightly packed business district of the city was flooded to depths of 4 to 8 feet with polluted salt water.

B. Recurring Losses. Following the record floods of 1954 and 1955, flood damage surveys were conducted in all parts of the basin which had been affected. For the riverine portion of the basin additional damage surveys of a review nature were made in areas of concentration of losses in 1959-1960 to determine the need and justification for providing local protective flood works. Review surveys of seven areas were made in the period 1969-1971 in connection with applications made for Section 205 studies. Economic feasibility was lacking in all the areas reviewed.

In the tidal portion of the basin a review survey of damage potential was made in 1963-1964 in connection with a survey report on hurricane protection for Narragansett Bay.

Recurring losses in the riverine portion of the basin in a recurrence of the August 1955 flood would amount to $26.3 million under 1972 conditions. These losses reflect the construction, in the interim since 1955, of the Worcester Diversion project, West Hill Dam and Reservoir, and the Upper and Lower Woonsocket Local Protection projects. These projects would prevent damages of $88.8 million with a recurring August 1955 event.

Recurring losses in the tidal reaches of the basin would be minor due to the operation of Fox Point Hurricane Barrier constructed in the early 1960's to prevent tidal flooding for the major portion of Providence. In a recurring 1954 event the barrier would prevent damages of $46.4 million.

C. Damage Reviews. There is a need for flood damage surveys on many of the tributaries of the basins in the Providence Group. For instance, the main stem of the Blackstone River has been well covered but there has been little, if any, investigation of the tributaries since 1956.

IX. *SOLUTIONS UNDER CONSIDERATION*

A. General. Major flood damages have been experienced within the Providence River Group watershed in 1954 - 1955 and most recently in 1968. In addition certain reaches of the various rivers have been subjected to almost annual flooding during spring run-off conditions. The need for additional flood protection within the watershed has been found to be of paramount importance. Consequently it is essential that a plan for a flood management program be investigated to afford flood relief to areas subjected to continuing flood damages. Both structural and non-structural measures must be examined for their role in resolving or alleviating these flood hazard problems.

Since the beginning of the study, many avenues of approach to resolution of the problem have been investigated. Many potential solutions were eliminated early in the investigation because they were totally infeasible or inadequate. However, realizing a final choice of measures should be made on parameters other than economic cost alone, the preliminary analysis has brought forth many potential solutions. Although some measures considered would not be instituted at the Federal level, they could fulfill some of the flood control needs of the area and could be implemented by local government. Therefore, the study will address itself to analyzing and preparing a balanced flood management plan involving the best possible solutions to the flood problems of the basin. Impacts on the well-being of the people, on the environment, and on the regional and national economic development will be evaluated for each of the solutions.

B. Measures. One method of alleviating flood problems is by construction of flood control structures, either water impounding reservoirs and/or dikes and walls, or a combination of the two. This is the structural method. Areas that are sparsely developed in many cases lend themselves to non-structural solutions. In the Providence River Group watershed there is no one particular solution to the flood problem. A combination of structural and non-structural elements appears to be the most logical approach to remedying the flood hazard situation. The structural measures would reduce or eliminate damages to existing structures and non-structural measures would prevent future development in flood prone areas, thus both solutions tend to complement one another.

C. Structural Measures. Methods of controlling floods by structural means which must be thoroughly investigated are grouped as follows:

1. Reservoirs. These consist of water impoundments located at strategic points within the watershed which would provide the greatest amount of flood protection. Understandably, the construction of a reservoir is at times unpopular with the public. It sometimes: inconveniences

people; temporarily upsets the community; and may affect the sociological and ecological aspects of the area. However, in specific localities a reservoir's effectiveness in reducing flood stages and alleviating damages to many communities in a watershed can be a preferred solution.

One important factor of flood control reservoirs which should not be overlooked is their ability to satisfy other needs. Water supply, water oriented recreation, and low flow augmentation for fish and wildlife and water quality enhancement can be compatible with flood control operations. Using reservoirs to satisfy multiple objectives results in greater utilization of the available natural resources within the watershed.

On the basis of the damage area data available from previous and new studies, a preliminary review indicates that four potential reservoirs merit further study. These sites are as follows:

(a) Moshassuck River Lake. This water impoundment would be located on the Moshassuck River in the town of Lincoln, northwesterly and directly north of Central Falls and Pawtucket, Rhode Island, respectively. The main purpose of the reservoir would be for storage to alleviate flood damages to the industrial and commercial establishments located along the middle reaches of the Moshassuck River watershed. Also, the reservoir would have the capability of satisfying other interrelated water needs, such as recreation and water supply or low flow augmentation.

With water supply as an added function, recreational activities would need to be regulated to conform to existing State laws, however, inclusion of non-contact water sports could be incorporated with the existing recreation facilities at Lincoln Woods State Park abutting the project on the southwesterly periphery of the reservoir. In addition, other beneficial uses, such as low flow augmentation for fish and wildlife enhancement and stream water quality improvement may show merit and should be carefully investigated.

Based on findings to date, the dam could consist of a rolled earthfill structure 100 feet high which would control eight inches of run-off from an intercepted drainage area of approximately five square miles. The reservoir as contemplated could impound a total storage of 11,400 acre-feet, with about 1,800 acre-feet and 160 acres of surface area reserved for conservation purposes. Approximately 7,400 acre-feet could be utilized to yield a dependable water supply capability of 4 million gallons a day (mgd), with the water supply pool providing a water surface area of 338 acres and a shoreline of about 3 miles for non-contact recreational activities.

This site is currently under investigation by the U. S. Department of Agriculture, Soil Conservation Service (SCS). Recently nine Rhode Island communities in the Woonasquatucket and Moshassuck watersheds have made a request for Soil Conservation Service assistance under Public Law 566. Pursuant to Executive Order 10913, tentative authorization for a plan of study, starting on 1 July 1972 has been granted subject to coordination with Corps of Engineers' studies. Pending the outcome of the SCS study, this office is holding Moshassuck River Reservoir site in abeyance, while maintaining close liaison and coordination with that study.

(b) Mapleville Lake. This project would be located in northwestern Rhode Island within the towns of Burrillville and Glocester and is under consideration as a vital link in the flood control study of the Blackstone River sub-watershed. It could also provide an entirely new water-oriented recreation development to the area. As presently considered, the project has been examined for these dual functions. The site does offer an opportunity to meet the present and future water supply demands for the northern part of the State of Rhode Island. With the implementation of the State Water Quality Standards, raising this stretch of the Chepachet River from its present Class C to B water, water supply could be substituted for recreation at a later date. With proper treatment and certain land use restrictions, the existing water quality problem could be remedied resulting in potable drinking water for immediate use. Further investigation to evaluate the water supply potential at this site will be pursued in the interim report stage. The dam could consist of a rolled earthfill structure, 70 feet high, situated across the Chepachet River just upstream of the upper extremities of Gilleran Pond, or about one quarter of a mile southerly of the village of Mapleville. The reservoir at full flood control pool would extend to near the village of Chepachet at U. S. Route 44.

The tentative total storage capacity of the project would be 12,700 acre-feet with 6,240 acre-feet, equivalent to six inches of run-off from a watershed of 19.5 square miles, reserved for flood control. The recreation pool could be established with a surface area of approximately 410 acres yielding a shoreline of about 8 miles. Storage releases to meet low flow augmentation needs, if necessary, would have to be made from the recreation pool. This could be accomplished without seriously interferring with the recreational development.

(c) Nipmuck River Lake. This reservoir proposal would be located along the Nipmuck River in the town of Burrillville, Rhode Island and would extend upstream across the Rhode Island-Massachusetts State line into the town of Douglas, Massachusetts.

The Nipmuck River, a tributary of the Pascoag and Branch Rivers, is one of the few remaining unspoiled streams in the State of Rhode Island. It has Class A water which makes it a prime source for meeting future water supply needs for the northern part of the State of Rhode Island.

Cognizant of the long range water supply needs and the potential of the Nipmuck River watershed, a multiple-purpose project consisting of water supply as an addition to flood control and recreation is under investigation. Advocation of such a proposal for water supply could be very effective in assuring that future land development conforms with the water supply objective.

Assuming that the water supply function is not implemented until some time after the project becomes operational, the 840 acre pool of the intended water supply storage with a shoreline of 7.5 miles, could be utilized for water oriented recreation activities. As the need for water increases, recreation would then have to be limited to non-contact or associated activities. It must be realized that there would be certain sociological implications involved in the conversion of use.

The optimum storage capability of the project would be approximately 28,400 acre-feet with a surface area of 970 acres. Of this amount, 5,200 acre-feet, equivalent to 6 inches of run-off from a watershed of 16.3 square miles, would be reserved for flood control. The water supply storage, amounting to 23,200 acre-feet of which 4,900 acre-feet would be set aside as a conservation storage, would be capable of yielding a dependable flow equivalent to 14.4 mgd.

This proposal, with its multiple-purpose aspects, is very preliminary. It has been included in this stage of the report because it merits further investigation. Studies to determine its optimum potential development in conformance with projected plans of the State of Rhode Island will be fully explored.

(d) Lackey Lake. This project would be located on the Mumford River in the towns of Douglas, Uxbridge, Sutton, and Northbridge, Massachusetts. The damsite, straddling the Sutton-Northbridge town line within the confines of Whitins Pond, would be located approximately 2,000 feet downstream of Lackey Pond, and 5 miles westerly of the village of Whitinsville, Massachusetts.

In a previous study, this reservoir was conceived as a multiple purpose project for flood control, recreation, and low flow augmentation. At that time the project was not economically justified. However, results of that study identified an array of interrelated water resource needs within the watershed. Since then, particularly because of damages caused by the recent flood of March 1968, Lackey Lake has become more desirable in providing a degree of flood control relief to downstream communities in both Massachusetts and Rhode Island.

In light of the water resource needs and potential availability, further studies to determine this project's feasibility and its public acceptance will be required. As tentatively contemplated the project would consist of a 65-foot rolled earthfill structure which would impound a maximum flood control storage of 10,700 acre-feet, equivalent to 6 inches of run-off from an upstream drainage area of 33.3 square miles. A summer conservation pool would be maintained for recreational development and possible augmentation of minimum flows. This would be done in order to enhance the downstream fishery and improve the water quality along the Mumford and Blackstone Rivers.

2. Local Protection Projects. This approach involves a system or a combination of flood walls, dikes, and appurtenant facilities for the protection of commercial, industrial, or residential developments against flood flows. Because of its nature, a local protection project eliminates flooding only at a single improvement or a localized group of improvements.

Recently a field survey was made throughout the watershed to determine locations appropriate for this type of protection. From this preliminary investigation, there are indications that some areas may have economically justified projects. For example, there are locations in both Grafton, Massachusetts and Pawtucket, Rhode Island which could result in Local Protection Projects. However, numerous other areas have sustained flood losses and are very prone to further flood losses. They are so dispersed that the construction of protection works may be marginal on an economic basis. More detailed investigations of these areas are necessary to determine the potential which local protection works could play. Such detailed studies will be pursued in the interim report stage.

3. Modification of Existing Lakes, Ponds, or Reservoirs. In the Providence River Group watershed there are numerous water impoundments which were developed by manufacturing concerns for use as process water and for power production. In recent decades, nationally and within the watershed there has been a trend toward the abandonment of these smaller hydroelectric power installations with mills now purchasing power from public utilities.

There is little need for impoundments for industrial and commercial uses because of modern technology. This factor, together with the decline and exodus of the textile industry from the area, have caused many of the ponds to be no longer used for their original purposes. Some of these water impoundments have been abandoned and others have completely exceeded their usefulness.

Based on preliminary studies, it appears that some of these impoundments hold a possibility for modification to provide a measure of flood protection. For example, sometimes it is not necessary to store large volumes of flood waters; a small amount may be sufficient to retard peak flow long enough to desynchronize tributary flows from the flood peaks on the major rivers. Detailed studies of certain existing water impoundments along tributary streams for conversion to flood control purposes are necessary to evaluate this potential and will be considered in the interim report stage.

4. Channel Improvement. The channel conditions of the major streams of this watershed have been neglected to such a degree that their deterioration has substantially affected their hydraulic efficiency. A recent survey of the areas found that a large part of the flooding conditions has been aggravated by siltation; riverbank and lowland encroachment through disposal of solid waste; inadequate bridge openings; and a general over-all neglect in the removal of vegetation and accumulated debris.

Siltation within the old neglected mill dams, originally intended for power generation and for process water, has caused restricted pondage resulting in widespread overflowing and a consequent rise of flood water levels. In addition, intermittent sections of the river have been converted into stagnant marshes, because of the impedance to normal river flow . With the occurrence of minor flood flows, overtopping of the river banks and inundation of inhabited low lying land is becoming more frequent and flood damages are rapidly increasing.

Encroachment on the channel in the watershed occurs principally with the utilization of the marshes, swamps, and other lowlying areas as dumping grounds for refuse. When solid waste, including cars, refrigerators, etc., are disposed upon river banks and adjacent lowlands, this refuse becomes destined for the waterways where it can lodge itself at constricted points resulting in serious blockage and backwater conditions.

On most of the major streams, within the watershed, bridges, culverts, and channel approaches act as hydraulic controls. They appear adequate and do not obstruct normal river flows. However, as evidenced during previous flood stages, many of these structures act as dams, trapping debris and causing a major restriction to the river channel. This condition is further aggravated by uncontrolled vegetation growth within and adjacent to the river channel. This is particularly evident near the approaches to the structures. To evaluate the severity of these channel constrictions detailed hydrological studies will be required.

A substantial amount of flood damages therefore can be attributed to the deterioration of the waterways. In the interim report stage, an in-depth study, examining a rehabilitation program for improving these major waterways will be assessed. From a standpoint of Federal assistance, under current guidelines, Federal participation may be limited for solutions considered in this measure. However, information developed in this study element can be utilized by State and local interests in the implementation of a comprehensive flood management program.

Channel improvements should consider at least the following measures:

(1) Adequate controls for rubbish disposal and a general clean-up campaign. Existing laws or ordinances to control the encroachment of flood prone areas by refuse disposal, need to be evaluated. Also, legal means should be instituted for implementing an enforcible clean-up campaign and for continuing a surveillance program.

(2) Channel Modification. Many of the major waterways are presently subjected to annual spring flooding. Unless some form of channel modification is initiated, the frequency of flooding and subsequent flood losses will increase at an alarming rate.

Various methods should be considered for this restoration work.

(a) Possible elimination of abrupt turns and oxbows.
(b) Widening and deepening of certain stretches of river.
(c) Improvement of waterway areas at bridges and culverts.
(d) Selective planting and/or revetment works for alleviating erosion problems.
(e) Removal of shoals, sandbars, and islands impeding minor flood flows.
(f) Removal of vegetation, overhanging trees, shrubs, and accumulated debris at critical points.

(3) Removal of Dams. An analysis will be made of possible channel improvement by means of dam removal, modification, or re-regulation. Dams which have been selected for this analysis are located along the main stem of the Blackstone River from Pawtucket, Rhode Island to Worcester, Massachusetts; and along the Woonasquatucket River from Providence to Smithfield, Rhode Island.

(4) Diversion of Flood Waters. An evaluation will be made of the possibilities of diversion of flood flows around heavily congested flood prone areas. This would also include the inter-basin diversion of flood flows. An example of this method is the existing Worcester Diversion, built by the Corps of Engineers, in the Blackstone River Basin. This project directs flood flows, originating from a 30 square mile drainage area upstream of Worcester, around that city, via a tunnel and channel downstream to the Blackstone River.

5. Flood Proofing. There are many areas in the watershed wherein large scale structural methods of protection against flood losses would be economically infeasible and use of non-structural solutions would not be possible. For example, an isolated mill may be subjected to periodic and minor flooding. Here, partial bricking of windows, relocation of entrances, and waterproofing foundations may be sufficient to provide the needed flood protection. In the case of isolated residential properties, waterproofing basements, together with sump pump facilities may be the only economical solution available. Although the Federal Government cannot provide the necessary funds for implementing most of these flood proofing methods, the Corps of Engineers can provide, at the request of individuals, through their municipal government, free technical assistance by delineating flood probability and stages for the area of concern. It is expected that such flooding information developed in the interim report stage will be utilized extensively by local interests.

6. Urban Redevelopment. Urban redevelopment presents another opportunity for communities to remove developments from flood plains and place them in secure areas, safe from floods, and to make sure that new construction in the flood plains is designed to withstand flooding.

During the course of the interim report study, upon request, the evaluation of flood hazard areas as they relate to urban redevelopment will be fully investigated. Communities contemplating or actually planning urban redevelopment will be made aware of the technical assistance available to them.

7. Small Watershed Treatment. Under Public Law 566, the small watershed program which was enacted by Congress in 1954, localities which are able to demonstrate that multiple-purpose watershed projects can serve as an effective means in controlling land use and water problems for rural and urban communities can apply for Federal assistance. PL 566 projects are handled by the U. S. Department of Agriculture, Soil Conservation Service (SCS). In the Providence River watershed there are presently two such studies in progress, one on the Woonasquatucket River watershed, including the Moshassuck River, and a second on the Ten Mile watershed. Both studies will be coordinated with studies under way by the Corps of Engineers.

D. Non-Structural Measures.

Since earliest times, man has encroached upon the flood plains of rivers and streams. Today, with increasing population and accompanying residential, commercial, and industrial development, encroachment on the flood plains is taking place at an alarming rate. There is a need therefore for a balanced approach to reduction of flood damage, one in which non-structural measures such as flood plain zoning play a companion role to structural solutions.

Non-structural measures revolve around control of the people rather than the water in the flood plain, and can be an effective tool in reducing flood damages within this watershed. Such measures include flood forecasting, evacuation, flood plain zoning, and/or regulations. With adequate storm warning and flood forecasting, the residences, industrial, and commercial establishments in low-lying areas are able to prepare defenses against flooding in the watershed.

Evacuation measures involve the identification and the preparation of plans for the evacuation of people from areas that are prone to flooding. With adequate warning and strict enforcement, flood losses can be kept to a minimum and loss of life can be prevented.

Flood plain regulations can prevent additional construction on already developed flood plains, and can be a compelling force in avoiding a repetition of past building errors in less developed areas.

As evidenced in the preliminary assessment of this watershed, flood plain regulation is considered to be the most effective non-structural means of flood damage reduction. To fully understand its importance, regulatory means must be subdivided into two major programs: Flood Plain Zoning; and Subdivision Regulations and/or Building Codes.

1. Flood Plain Zoning: This normally involves the enactment of ordinances which are legal tools to implement and enforce detailed plans resulting from land use planning programs. These programs usually involve the preparation of maps and profiles which delineate the flood hazard areas These are provided by Federal agencies for the local government so that zoning can be established.

Cognizant of these planning programs, the cities of Pawtucket and Central Falls, and the towns of Lincoln and Cumberland have requested Flood Plain Information studies on the Blackstone River. These studies have been recently completed and submitted to those communities for implementation. The town of Auburn, Massachusetts has submitted a similar request and studies will subsequently be under way. Under the authority of the National Flood Insurance Act, four Rhode Island cities, Providence, Pawtucket, Central Falls, and Woonsocket; and the towns of Swansea and Auburn, Massachusetts have applied for and received assistance under this act. Two other towns in Rhode Island, namely; Smithfield and East Providence, have requested similar assistance and these studies are presently in progress.

2. Subdivision Regulations and/or Building Codes: These methods can be used by local governments to specify the manner in which land may be used. They are an effective means of controlling construction in presently undeveloped flood plain areas. Their proper application can benefit the public health and welfare of the people and can also reduce municipal costs during flood periods. Within the interim report study an examination of existing regulations will be made where appropriate, recommendations will be made for changes or additions to these regulations.

E. Coordination with Southeastern New England Study. Because the SENE Study will receive the inputs and/or review by approximately 45 Federal and State agencies, the solutions under consideration by the PNB Study for the Providence River Group watershed, whether single or multiple-purpose in nature, will be closely coordinated with the SENE Study to insure that the PD report recommendations would not preclude opportunities for enhancement of related resource uses which may be identified by the SENE Study.

For example, the SENE Study will identify existing land use, zoning ordinances, and flood plain restrictions for each community within the study area. Land use delineations at a scale of 1:24,000 are scheduled to be available for the Massachusetts portion of the SENE area in November 1972 and for the Rhode Island portion in January 1973. These maps will enable the comparison of existing patterns of development with past development, which in turn can be used as a tool for identifying future water and related land use pressures.

The SENE Study will also attempt to match the needs and supply of all water resource uses in order to effect a balance between the enhancement of environmental quality and the enhancement of the economic base. While the SENE Study will evaluate the problems and needs for the entire Southeastern New England area, the PNB Study as a more detailed level C study, would explore many of these needs in greater depth than would be possible by the SENE Study. The two studies would be mutually dependent upon each other. Information would be freely exchanged by the two study groups in order to minimize duplication of effort.

X. ENVIRONMENTAL PROFILE

A. Introduction

The Providence River Group, a complex of interior watersheds draining into the upper portion of Narragansett Bay, consists of two interstate sub-basins and two intrastate sub-basins. The two interstate sub-basins are the Blackstone and Ten Mile Rivers. The two intrastate basins are the Moshassuck and the Woonasquatucket Rivers.

The Blackstone and Ten Mile Rivers were the subjects of a conference held under the provisions of the Federal Water Pollution Control Act, concerning the pollution of interstate waters. The 1965 conference presented evidence that domestic, municipal, and industrial wastes were endangering the health and welfare of the people in the sub-basins. Programs for abating pollution were reviewed at the second session in 1968 and steps to protect these rivers were initiated by Massachusetts and Rhode Island.

The intrastate Moshassuck and Woonasquatucket Rivers have not yet been the subjects of a conference; however, the Rhode Island Department of Health, Division of Water Pollution Control, has investigated and classified their present and anticipated water qualities. Pollution abatement programs are presently under way.

Where possible the PNB Study will assess the feasibility or advisability of providing additional resource opportunities and stimulating economic activity through increasing water quality levels beyond the anticipated classifications. For instance, water-dependent industries attracted to the basin because of increased water quality would help relieve the major employment void left by the declining textile industry in south-central Massachusetts and northern Rhode Island. In addition, some recreational activities such as boating and fishing, along the main stem and in the estuary, would be improved for outdoor enthusiasts. Regional wastewater management within the watershed would also have a direct beneficial effect on the marine environment of the Seekonk River and Narragansett Bay, a major focal point of recreational activities in southern New England.

B. History

All the Narragansett Bay tributaries once supported notable spawning runs of anadromous fish, especially the American shad. In addition to American shad, the Blackstone River auspiciously supported Atlantic salmon. They once travelled upstream as far as the "Falls" at Pawtucket, Rhode Island.

The colonists first used the waters of the Blackstone River to power a grist mill built in 1671. By the early 1700's, many grist mills were in operation throughout the Providence River Group. The power of these mills was supplied by low head dams built throughout the sub-basins. By the 20th century, industrialization accounted for over 100 dams in the Blackstone River.

Currently, the Blackstone River receives domestic and municipal wastes; wool scouring, dying, and finishing wastes; rubber processing and paper coating wastes; and pickling liquors. The Ten Mile River receives domestic, municipal, plating, pickling, chemical, and textile wastes. The Moshassuck and Woonasquatucket River Basins are also residential and industrial centers. Approximately 50 percent of the land in the Moshassuck River Basin is classified as developed; only 3 percent of the land is unsuitable for future development. The Moshassuck River Basin is the major industrial area in Rhode Island. Land development in the Woonasquatucket River Basin is principally residential.

The Blackstone River was used for navigation until 1848, when the barge canal was abandoned. Today, only the 7-mile long tidal Seekonk River, the receiving stream of the Blackstone, is navigable.

C. Recreation

The recreational activities in the Providence River Group consist mainly of scenic, historical, educational, and religious points of interest; golf courses; State parks and forests; freshwater fishing, boating and swimming.

The majority of the recreational opportunities in the Blackstone River watershed are confined to the tributaries. Main stem recreational opportunities are limited to a few historical points of interest, a few golf courses, and a State forest. No bathing beaches are present along the main stem. A yacht club and a State park are situated along the Seekonk River, the receiving stream of the Blackstone River. Much more diversified recreation is available along the tributaries. They offer historical, cultural, and educational points of interest; scenic vistas; a ski area; hiking trails; archery ranges; bathing beaches; boating; fishing; camping and hunting areas.

The recreational facilities in the Ten Mile River Basin consist of historical and religious points of interest, golf courses, State parks and forests, children's camps and a fish hatchery. No bathing beaches, and only a few other types of recreational areas, are located along the main stem. Recreation along the river is limited to a State park, a historical point of interest and a few golf courses.

A large State park, located near the headwaters of the Moshassuck River provides the only recreation along the main stem. The State park provides the public with an opportunity for horseback riding, swimming, boating, and picnicking. Other recreational activities within the drainage basin include historic and educational points of interest, bathing beaches, scenic views, golf courses and a race track.

There are eleven water-related recreational areas (two State parks, seven bathing beaches, one camping site and one boat launching site) located along the Woonasquatucket River Basin. Other recreational activities within the basin include historical and educational points of interest and golf courses.

D. Water Quality

The Water Quality Act of 1965 authorized every State to establish interstate water quality standards. The standards now being implemented by the States of Massachusetts and Rhode Island were adopted in 1967. The water quality standards were based on public health, recreational, economic and social considerations in addition to fish and wildlife protection and propagation factors. The adopted standards classify streams according to present use and practicable future use.

Class A water, which is of uniformly excellent quality, is designated for use in public water supplies. Class B water, acceptable for public water supply with appropriate treatment, may also be used for agricultural and industrial cooling and processing. It is suitable for water contact recreational purposes and it is excellent for fish and wildlife. Class B water is of excellent aesthetic value. Class C water is acceptable for certain industrial cooling and process water. Under some conditions, it is acceptable for public water supply use when appropriately treated. Class C water has good aesthetic quality and it is suitable for recreational boating. It provides a habitat for fish and wildlife indigenous to the region. Class D water is suitable for certain industrial processing and cooling, power, and navigation. It is suitable for aesthetic enjoyment. Class D is assigned only when higher water use cannot be attained after appropriate treatment. Waters that fall below Class D are considered to be in a nuisance condition.

1. Blackstone River

The Blackstone River has the following classifications:

Municipal Reaches	Present Classification	Anticipated Classification
Massachusetts		
Worcester	*	C
Millbury & Sutton	*	D
Grafton, Northbridge Uxbridge & Millville	D	C
Rhode Island		
Woonsocket	D & *	C
Cumberland & Lincoln	*, D & C	C
Central Falls & Pawtucket	C	C

*Nuisance Condition

The Seekonk River has a present sea water classification of SE. It is considered in a nuisance condition unsuitable for most uses. The river has a future classification of SD. It will be suitable for navigation, industrial cooling, fish migration, and good aesthetic value.

Sanitary survey reports of the early 1900's indicated that the Blackstone River, below Worcester, Massachusetts was little more than an open sewer. Today, the most significant types of wastes in the river are municipal sewage and woolen textile wastes. Also present in the river are rubber processing wastes, paper coating wastes, and pickling liquors. Sewage is the major source of bacterial pollution. There are 12 major contributors of coliform bacteria, 7 in Massachusetts and 5 in Rhode Island. Worcester, Massachusetts and Woonsocket, Rhode Island are the two largest sources of bacterial pollution.

Approximately 58 percent of the total oxygen demand in the river originates from sewage and industrial wastes in Rhode Island. The remainder of the total oxygen demand, 42 percent, originates in Massachusetts. The oxygen demand of industrial wastes exceed the demands from sewage. The largest, industrial, oxygen demanding load enters the river at Woonsocket, Rhode Island. The second largest industrial load is from the Branch River. Massachusetts contributes 35 percent of the oxygen demand from industrial wastes.

The major tributaries of the Blackstone, in Massachusetts, presently range from a nuisance condition to Class B. Their anticipated future classification is Class B. The major tributaries in Rhode Island range from a nuisance condition to Class A. They have anticipated future classifications ranging from Class D to A.

2. Ten Mile River

The Ten Mile River has the following classifications:

Municipal Reaches	Present Classification	Anticipated Classification
Massachusetts		
Plainville & No. Attleboro	B & C	B
Attleboro & Seekonk	C & D	C
Rhode Island		
Pawtucket	* & D	C
E. Providence	D & C	C & B

*Nuisance Condition

Approximately 19 miles of the 20-mile long Ten Mile River are considered degraded. Only the headwaters are presently classified as B water. Discharges to the river consist of municipal and industrial wastes. The industrial wastes consist of textile, chemical, pickling and metal plating wastes. The most severely degraded reach of the river is below Attleboro, Massachusetts, near the State line.

Attleboro and North Attleboro, Massachusetts are the two largest sources of municipal wastes. Total coliform bacteria densities were once measured at 5,500 MPN/100 ml. upstream of Attleboro and nearly 8 million MPN/100 ml. near the State line. In a 1964 study, the mean total coliform density at Turner Reservoir, once the water supply for the city of East Providence, was 1,500 MPN/100 ml.

Approximately 95 percent of the total oxygen demand in the river is from Massachusetts; the remaining 5 percent is from Rhode Island. The reduction of dissolved oxygen in the river is due to pollution from approximately four industries and two municipal sewage treatment plants. Approximately 83 percent of the industries discharging oxygen consuming wastes are in Massachusetts. There are numerous metal plating plants along the Ten Mile River which discharge heavy metals, included are cyanides of gold, silver, rubidium, chromium, nickel, copper, and zinc.

The major tributaries of the Ten Mile River have water classifications varying from A to D, with anticipated future classifications between A and C.

3. Moshassuck River

The Moshassuck River has the following classifications:

Municipal Reaches	Present Classification	Anticipated Classification
Rhode Island		
Lincoln	B & C	B & C
North Providence	C	C
Providence	C	C

The principal wastes in the Moshassuck River are sanitary sewage, cooling water discharge, and metal plating wastes.

The major tributary is presently classified as B and C water, with an anticipated future classification of B.

4. Woonasquatucket River

The Woonasquatucket River has the following classifications:

Municipal Reaches	Present Classification	Anticipated Classification
Rhode Island		
North Smithfield	B	B
Smithfield	B & C	B & C
Johnston & North Providence	C	C
Providence	C	C

The Woonasquatucket River is degraded by municipal and industrial wastes consisting of sanitary, laundromat, cooling water, acid, caustic and trace metal wastes. The major tributaries are presently classified as B, C, D, and nuisance waters. Their anticipated future classifications will be B and C.

E. Aquatic Life

Pollution in the Providence River Group has severely limited the aquatic organisms in the main stems. Oysters were once abundant in the upper end of the Providence River and in the Seekonk River. Harvesting oysters from "nursery areas" dated back to the colonial period. It is believed that this upper area played a significant role in maintaining oyster populations throughout Narragansett Bay. The decline of the oyster industry in Rhode Island paralleled the early 1900's industrial growth within the Narragansett Bay drainage area. Presumably, predators, pollution, and hurricanes were important factors contributing to their disappearance.

1. Blackstone River

Sewage enters along the entire length of the Blackstone River. The number of sewage associated coliform bacteria near the Massachusetts-Rhode Island State line has been measured at 10 times greater than the maximum allowable limit for general recreational use. Approximately 67 percent of the bacterial pollution in the river originates in Massachusetts. In a reach below Woonsocket, Rhode Island the total coliform density has been measured at 30 percent greater than the density expected in raw sewage.

Aquatic plants are abundant in numerous reaches of the main stem of the river. Some plants are covered with slimes of bacteria and filamentous algae. The river bottom also has sludge deposits of wool fibers and oily substances covered with slime growths.

A variable number of bottom organisms exist throughout the entire length of the Blackstone River. In a reach downstream of Worcester, only one kind of bottom organism - sludgeworms - exist. Five or six kinds of bottom organisms have been identified near the State line. The lower reaches of the Blackstone River support as many as 11 kinds of bottom organisms, but no clean water forms are present.

The Blackstone River is generally considered a warm water fishery, with inferior species of fish found in the main stem. The fish presently found in the main stream are suckers, carp, eels, and bullheads. In 1940, a fish population survey revealed no game fish were present in the Massachusetts portion of the main stem. More recently, however, bass, pickerel, perch, and bluegills were killed during the construction of a bridge in Albion, Rhode Island. The seining of golden shiners for bait occurs on the river from Woonsocket to Pawtucket, Rhode Island. The present fish community in the main stem seems to be more diversified than in 1940.

The aquatic life in many tributaries shows the effects of moderate pollution. A greater variety of bottom organisms are present, including some clean water species. Many of the smaller tributaries are classified as cold water fisheries. There are approximately 21 Massachusetts ponds and tributaries, and 14 Rhode Island ponds and tributaries that are annually stocked with trout. Consequently, there are various pools along the main stem, near the mouths of the tributaries, which support small communities of game fish.

2. Ten Mile River

Attleboro and North Attleboro, Massachusetts are two major sources of bacterial pollution to the Ten Mile River. A total coliform bacterial density 1,500 times greater than the general recreational objective has been measured in the river.

Algae blooms producing greenish color characteristics in the water have been recorded. Many stretches of the river exhibit dense growths of aquatic plants and extensive sludge deposits covered with slime and grease.

Progressing downstream from the headwaters, clean water associated bottom organisms are reduced and then eliminated. Numerous species of pollution associated bottom organisms, dominated by rattail maggot, sludgeworms, and midges are present in the Ten Mile River. Eleven species of pollution associated organisms have been identified in the lower reaches of the river.

Portions of the Ten Mile River are classified as warm water fisheries. The fish community below Plainville, Massachusetts has consisted of inferior species including some reaches possibly devoid of any fish. The main stem is presumably populated with suckers, carp, eels, and bullheads. The major tributary, the Bungay River, is a cold water fishery. Trout are stocked in the Bungay River; the Ten Mile River above Plainville, Massachusetts; and in the Ten Mile River below the Turner Reservoir in East Providence, Rhode Island.

3. Moshassuck and Woonasquatucket Rivers

Like the two interstate streams of the PD group, the Moshassuck and the Woonasquatucket Rivers support limited aquatic life. The lower reaches of these rivers are congested with aquatic plants too dense for adequate fish survival. Generally, the tributaries, ponds, and impoundments in the upper reaches of these sub-basins are best suited for warm water fish. Good warm water fisheries produce smallmouth and largemouth bass, chain pickerel, white perch, yellow perch, and bullheads. Many of the fish communities in the ponds and impoundments throughout these sub-basins possibly exhibit stunted populations. Each main stem has one tributary which is stocked with trout.

F. Wildlife

The Providence River Group consists of three river basins that pass through industrial, commercial, residential, and rural areas containing a variety of brush cover and woodlands.

The game harvest of this watershed complex consists of game birds, fur animals, and deer. The game birds are represented by the pheasant, ruffed grouse, quail, and woodcock. The fur animals include cottontails, hares, opposums, skunks, raccoons, foxes, and squirrels. Deer are present but do not occur in large numbers within the watershed. They do not attain importance as a wildlife resource.

Aquatic wildlife are also represented in the PD watershed. The wetlands in the watershed consist of a number of small, scattered marshes and swamps which possess a high value to waterfowl and semi-aquatic fur animals. Wild ducks, muskrats, and mink rely on interior wetlands to supply them with food and shelter. In addition, wetlands are also excellent locations for breeding grounds.

G. Aesthetics

The watercourses of the PD group consist of urban and rural environments. The lower reaches of the rivers are industrial, commercial, and residential areas. The rural upper reaches and tributaries are harmonious unions of woodland areas, agricultural areas, and residential areas occasionally interrupted by small commercial complexes.

The scenic vistas of the PD watersheds lack the height and distance necessary to expose river valley panoramas. Generally, the only sites which afford distance views of the rivers are from bridges. In the lower reaches, the river scene is dominated by unattractive industrial and commercial establishments. In the upper reaches, although the area is more scenic, lack of visual distance considerably reduces the effect of the view.

Like many river basins in New England, the PD rivers are not physically accessable. Lands adjacent to the rivers are owned by private citizens, and commercial and industrial businesses. Public access to the river is minimal. Often, in areas where the river is accessible, the watercourse is displeasing. A view from the river banks may reveal industrial effluents, sludge, slimes and assorted discarded debris. The psychological responses produced by smell, a sensory perception, plays an important role in determining the aesthetic quality of a river.

All of the rivers in the PD group are relatively narrow and consequently have little panoramic value. The most exciting qualities of a narrow river are its flow and bed characteristics. Generally, the slow flow of these rivers does not reveal the characteristics of their beds because of the high turbidity and color characteristics of the water.

The river bank is an important focal point of a riverscape, and the poor aesthetic quality of many reaches of these rivers is because of unattractive land/water interfaces. Often the flow is sluggish, the aquatic vegetation is excessive and the marginal landscape is poor.

Strong associations are formed by ephemeral effects. Reflections, fog, surface conditions and falling water play important influencing roles in determining the aesthetics of a watercourse. Combined with a variety of contextual landscaping, these attributes make the tributaries and upper reaches of the PD group more pleasing than the lower reaches. Visually, they are enhanced by spatial enclosure, a form of edge measurement.

Uncongested homes along the streams, silhouetted steeples above the tree tops, and water spilling over a pond dam combine to form a variety of effects, some approaching pastoral quality.

The most important variable in determining the aesthetic quality of a river is the amount of maintenance that the area obtains. Unfortunately, the repetitive theme presented by the main stems of the PD group is that of neglect, leading to the poor or mediocre over-all aesthetic qualities of the PD main stems.

H. Assessment Process

A preliminary environmental assessment of all potential flood control measures described in Section IX is under way. The environmental impact of all structural and non-structural flood control measures for the Providence River Group streams will be evaluated. Impact on natural, man-made, archeological, historical, recreational, aesthetic, social, and cultural resources of the affected areas will be investigated. The studies will delineate resolvable and unresolvable adverse effects, abatement measures and mitigation measures. Direct, indirect, qualitative, quantitative, short-term and long-term effects will be investigated. In addition, the cost of protective measures for mitigating, compensating, and eliminating environmental disruption will be considered. The deleterious effects of the potential flood control measures under investigation will be weighed against the beneficial effects and social values of the feasible flood control measures.

Structural solutions include reservoir formation by damming, local protection by diking, modification of existing reservoirs or ponds, channel improvements, removal of dams, diversion of flood waters, flood proofing, urban redevelopment and small watershed treatment. If reservoirs are recommended, an environmental assessment of the amount of land inundated, the affects on the local biota and the affects on water quality will be studied. Other environmental concerns will be water temperature variations, pool fluctuations, run-off inflows, water release, potential fisheries, construction activities, vegetation removal, revegetation, recreation and aesthetic design of dams. If local protection projects using dikes are recommended, an environmental assessment of the reorganization of the ecological niches in the watercourse, the decreased availability of space for biota establishments, erosion and siltation effects, and increased development of formerly flood prone areas will be studied. If other structural solutions such as the removal of dams, modification of existing ponds or reservoirs, channel improvements or diversion of flooding waters are recommended, dredging effects will be of interest. An environmental evaluation of the impact of short-term and long-term effects on the aquatic biota and water quality will be a major issue.

In addition to ecological considerations, structural and non-structural measures have important social and economic impacts which will also be considered.

XI. LOCAL SUPPORT AND DESIRES

On initiation of the Pawcatuck River and Narragansett Bay Drainage Basins Study, in early calendar year 1969, four public hearings were held, one each in Taunton and Uxbridge, Massachusetts; Providence and Kingston, Rhode Island. The purpose of these hearings was to afford individual citizens, municipal and State officials, and other Federal agencies an opportunity to present their views and desires concerning the need and extent of improvements on flood reduction measures and other interrelated water-oriented resources.

To supplement information received at the public meetings, and to fully evaluate and update the inventory of flood problem locations and related water resource needs, letters requesting such information were mailed to responsible local officials. Concurrently, numerous informal meetings with State agencies, the Pawtucket-Blackstone Valley Chamber of Commerce, and personal contacts with Federal agencies and individual citizens were initiated.

Since the initial hearings, additional requests for Federal assistance in solving specific flood problems have been received. Some of the requests have been considered under other existing authorities available to the Corps of Engineers, such as Section 205 of the Flood Control Act of 1948, as amended. Other requests received and processed came under the purview of the clearing and snagging authority as covered in Section 208 of the Flood Control Act of 1954, as amended; Section 14 of the 1946 Flood Control Act involving emergency bank slope protection; and PL 99 consisting of restoration of existing works.

Substantial local support has been growing steadily within the Providence River watershed. Recently the Pawtucket-Blackstone Valley Chamber of Commerce has expressed an interest, and has supported and been instrumental in the acceleration of the studies of the Providence River Watershed. That organization has offered encouragement and has disseminated information to local interests asking for their whole-hearted support. This has resulted in meetings becoming more fruitful with indications of general support and genuine willingness to participate in the investigation of the watershed.

XII. COORDINATION

In addition to close coordination with the Southeastern New England Study, as discussed at the end of Section IX, close liaison with the Massachusetts and Rhode Island State agencies has been and will be continually maintained through the representation of the Massachusetts Department of Water Resources and the Rhode Island Water Resources Board. Personal contacts and an exchange of ideas with other Federal agencies have been initiated. This particularly applies to the Rhode Island office of the Soil Conservation Service, Department of Agriculture, which has received an application involving nine Rhode Island communities for assistance under PL 566 for a study of the Woonasquatucket and Moshassuck River watersheds. Similarly, the Massachusetts office, Soil Conservation Service has also received an application for assistance for the Ten Mile River watershed. Both applications have been approved and preliminary investigations are either under way or scheduled for the immediate future.

Although the Corps' PNB Study authorization provides a proper vehicle for a systematic investigation of these previously mentioned urbanized watersheds, present funding and manpower capability do not permit the completion of a watershed plan as early as desired by local interests. Consequently, this office concurs with the undertaking of the PL 566 studies by the Soil Conservation Service. Such approval should not be construed as relieving this office of its responsibility as directed by the seven authorizing Congressional resolutions, but only as a means of expediting the study of the Providence River watershed. Close coordination has been maintained between the Corps and SCS in order to avoid duplication of effort and possible confusion among the local communities.

Coordination and liaison with the Pawtucket-Blackstone Valley Chamber of Commerce and governmental agencies at all levels will also be maintained. They and other local groups will be kept informed of any developments in the conduct of the studies. An added function to these studies will involve consultation with, and participation by, citizen groups in formulating the flood management plan for the areas under consideration.

XIII. ESTIMATED COSTS FOR PREPARATION OF INTERIM REPORT

The total cost of the PNB Study was estimated at $1.6 million. Of this amount it is estimated that $540,000 will be required to formulate a plan of development for the Providence River Group watershed.

The final report of the PD Group is scheduled for submission in Fiscal Year 1975, assuming receipt of adequate funds in Fiscal Years 1973, 1974, and 1975. Should a segment of the Providence River Group involving the Blackstone River watershed be expanded to include urban studies then the cost would have to be increased to reflect the change in mission.

The scope of work presently contemplated for this watershed is dependent on successful completion of the Soil Conservation Service's PL 566 investigations for the Woonasquatucket and Ten Mile River watersheds and the use of consultant engineers under contract for the Blackstone River watershed. Studies involving the Blackstone River watershed have been initiated and the first phase of work to be covered in Fiscal Year 1973 will be awarded in December 1972. The second and third phases of a contract to run concurrently in Fiscal Year 1974 and 1975 will be awarded as funds become available.

Upon completion of all three phases, the final report of the Blackstone River watershed, together with the Soil Conservation Service's PL 566 investigations for the Woonasquatucket and Ten Mile River watersheds will be combined and submitted in final form to Congress.

XIV. FINDINGS AND CONCLUSIONS

Population growth and urbanization in the Providence River Group watershed, have magnified land development problems in the suburban fringe areas of the core cities. A constantly improving highway transportation system serves present, and opens up new undeveloped areas of the watershed. It also provides greater commuting mobility between the urban and suburban communities. The metropolitan centers of Worcester and Providence, together with the valley communities along the Blackstone River, are also serviced by adequate rail freight facilities which are stimulating commercial and industrial expansion within a large segment of the watershed. A large percentage of the expansion has been at the expense of flood plains. Land changes have adversely affected the run-off characteristics of the watershed and the hydraulic efficiency of channels. In certain regions, significant natural valley storage has been lost. Unless flood plain management programs are instituted to temper or guide economic development, future flood losses will be severe.

There are many possible solutions for controlling future flood losses in the Providence River Group watershed; however, a preliminary analysis indicates that only a few may be economically feasible if singularly oriented toward flood control. The most

Viable solutions under consideration would be multiple purpose structural measures, together with a strong non-structural management program. There is no single solution, structural or non-structural which predominates. It is expected that the final plan will need to include all types of flood management if it is to be effective. Among the measures to be investigated in the interim report phase are:

- Four multiple-purpose reservoirs, namely, Nipmuck Mapleville, Lackey, and Moshassuck Lakes. (The latter being deferred pending completion of the SCS study in the Woonasquatucket watershed.)

- Local protection projects at critical damage centers, to be determined after a flood damage survey is completed.

- Modification of existing impoundments.

- Channel improvement, including removal of several dams along major streams.

- Diversion of flood waters.

- Flood proofing.

- Urban redevelopment.

- Small watershed treatment. (SCS projects for Woonasquatucket and Ten Mile watersheds.)

- Non-structural measures, identifying the importance of zoning critical flood plains as well as enforcement of good building codes.

XV. RECOMMENDATIONS

Because of the land development programs currently being carried out indiscriminately in various sectors of the flood plains, and the pressing needs for alleviating or reducing the flood problems as demonstrated by the local citizenry and supported by local and Congressional interests, it is recommended that preparation of an accelerated plan of development for the Providence River Group watershed as an interim segment of the PNB total study area be undertaken at an estimated total cost of $540,000.

It is estimated that a period of two and one-half years from submission of this reconnaissance report will be required for preparation of the interim report. Due to our staff limitations it is proposed to expedite the interim report of survey scope for the Blackstone River segment with the use of consultant engineers under contract, and would cover three phases to be completed by 1975.

The PD study would be closely coordinated with other on-going studies such as the Southeastern New England (SENE) Study and the Northeastern United States Water Supply (NEWS) Study and the Soil Conservation Service PL 566 study for the Woonasquatucket and Ten Mile River watersheds.

CORPS OF ENGINEERS U.S. ARMY